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THE POTENTIAL FOR ENGINEERED WOOD PRODUCTS IN ALBERTA'S RESIDENTIAL CONSTRUCTION

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THE POTENTIAL FOR ENGINEERED WOOD PRODUCTS IN ALBERTA'S RESIDENTIAL CONSTRUCTION

March 1991

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The views and conclusions expressed and the recommendations made in this report are entirely those of the authors and should not be construed as expressing the opinions of Alberta Municipal Affairs.

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FOREWORD

The project documented in this report received funding under the Innovative Housing Grants Program of Alberta Municipal Affairs. The Innovative Housing Grants Program is intended to encourage and assist housing research and development which will reduce housing costs, improve the quality and performance of dwelling units and subdivisions, or increase the long term viability and competitiveness of Alberta's housing industry.

The Program offers assistance to builders, developers, consulting firms, professionals, industry groups, building products manufacturers, municipal governments, educational institutions, non-profit groups and individuals. At this time, priority areas for investigation include building design, construction technology, energy conservation, site and subdivision design, site servicing technology, residential building product development or improvement and information technology.

As the type of project and level of resources vary from applicant to applicant, the resulting documents are also varied. Comments and suggestions on this report are welcome. Please send comments or requests for further information to:

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EXECUTIVE SUMMARY

The forestry and lumber industry plays a significant role within Alberta's economy in general and the residential construction industry in particular. However, competition from other construction materials and shrinking forest resources call for more competitive and efficiently utilized wood products.

The purpose of the project was to identify reinforced or modified wood technologies which have application in residential construction and can be commercially exploited by Alberta's manufacturers using Alberta's raw materials.

The project commenced with a preliminary literature and patent search to identify the available technologies in the area and those experts or research organizations who are actively working in this area. This was followed by a comprehensive consultation with external contacts and field investigations. A preliminary selection of potential engineered wood technologies was made and presented to a consultative meeting of manufacturers, builders, research institutes and government agencies to prioritize the potential engineered wood technologies . The final selection of five potential technologies was made by active practitioners in the research, manufacturing and construction industries and the future steps, such as research and marketing, were identified as necessary to facilitate the introduction of those technologies.

The top-rank technologies are chosen based on five criteria: 1) performance of the product; 2) current technical status of the technology; 3) availability of the product in Alberta; 4) economies of the product; 5) potential for export of the technology. The technologies and products identified are: particleboards, wood I-beams, parallel strand lumber, wood structural systems, and wood-plastic composites.

The findings from this study indicate that recent developments in reinforced and modified wood products, especially wood composite products and wood structural systems, present an unlimited opportunity for the forest and wood industries in Alberta. The future research and development of these technologies should emphasize the importance of the recovery rate and efficient use of the wood resources, energy efficiency of the new technologies, environmental friendliness of the products, and use of recycled materials in the potential products. In addition to strong research and development, comprehensive economic and marketing studies were found to be equally important to the eventual success of these new technologies.

1.0 INTRODUCTION

1.1 GENERAL

The forestry and lumber industry plays a significant role within Alberta's economy in general and the residential construction industry in particular. However, competition in the residential construction industry is intense. Without new ideas and new products, market share of the wood industry will suffer due to the shortage of timber resources and the increasing competition from other construction materials (1).

The idea of reinforcing timber is not new with early records dating back to the late 1800's. There have been patents on many varieties of reinforced wood and wood base material from as early as 1907 (2). Most of these ideas have not been developed commercially to date because the benefits have not outweighed the costs, the production technology has not been developed past the exploratory stage, and the national need for new and improved structural materials, due to shortages, has not been pressing. However, due to the strong competition in the market and shrinking forest resources in the 90's, it is time to have a new look at the area of modified structural lumber and its application in both residential construction and small scale commercial/industrial construction.

1.2 OBJECTIVES

The purpose of the project was to identify reinforced wood technologies which have application in residential construction, but which can be commercially exploited by Alberta's manufacturers using Alberta raw materials.

The objectives of this project were as follows:

1. Conduct an up-to-date literature and patent search of reinforced wood technologies.
2. In consultation with knowledgeable builders and wood manufacturers evaluate available or imminent technologies to identify those which appear to have application in Alberta.
3. Develop a priority list of technologies or products which merit further consideration and prepare work plans or research proposals for five of those selected which outline how they should be pursued in order to facilitate their eventual commercialization within Alberta.

1.3 SCOPE AND FOCUS

The motivations behind reinforced wood technologies are either performance-driven or price-driven. Traditionally, research and development of reinforced wood and wood base materials focused on lumber members and mostly on flexural members, such as flitch beams, to enhance performance of the members. The most popular reinforcements used in reinforced wood members in the past were steel, fiberglass, aluminum, wire reinforcement, and plastic (3). However, in the last decade engineered wood composites, such as waferboard, oriented strandboard, and Parallam, have developed rapidly into a new generation of wood products. High-yield or high-quality products are manufactured from wood resources with little or no commercial potential, such as mill residues or pulpwoods. This presents new opportunities to manufacture structural wood products, especially reinforced wood members, since little effort is needed to modify the engineered wood composites (4). With improving composite wood products and diminishing average log size, a new era of modified wood members and wood structural systems is evolving, such as I-beams (5) or stressed skin panels (6). There will be a focus on combining two or more wood products in such a way that the composite is more economical or will perform better than the individual components.

Three generations of engineered wood members, classified as reinforced wood components, wood composites, and built-up members or structural systems, were covered in this investigation. Conventional sawn lumber and glulam timber, as well as engineered wood composites, were also considered in this study. The investigation focused on the application of these evolving technologies to both the small scale commercial/industrial and the residential construction spheres of activity. Special attention was given to the applicability, cost competitiveness, and availability of the prospective products in Alberta.

1.4 RESEARCH METHODOLOGY

The project was divided into two phases and was designed as follows:

Phase I - Data Acquisition and Evaluation

a. Literature review - A comprehensive literature and patent search was conducted.

b. Evaluation - Identified information and technologies were evaluated against: i) performance of the reinforced members; ii) current technical status of the technology; iii) availability in

Alberta; iv) economies of the product; and v) potential for export. The evaluation focused on the application to small scale commercial/industrial and residential construction.

c. Technology selection - A comprehensive consultation with external experts and field investigations was undertaken to confirm and further the findings from above. Based on the information gathered, a preliminary selection of reinforced wood technologies was made.

Phase II - Industry Consultation, Prioritization and Final Report

a. Industry consultation - A summary of the wood reinforcing technologies identified in Phase I was prepared and presented to leading wood manufacturers, builders, research institutes, and government agencies.

b. Prioritization - Based on the results of the consultation meeting and the established evaluation criteria, the final selection of five potential engineered wood technologies was made and future steps to facilitate the introduction of those technologies were recommended. For those technologies which require further research before they can be commercialized, research plans and suggestions were provided.

1.5 REPORT OUTLINE

A comprehensive review and evaluation of existing literature on reinforced wood members is presented in Chapters 2, 3, and 4. Chapter 2 covers traditional reinforced wood components, which are normally limited to sawn lumber and glulam timber. Recent developments and research into wood composites are described in detail in Chapter 3. Chapter 4 looks at the potential of built-up members and composite structural systems. Each chapter starts with a general review of the performance and current status of available technologies and ends with a summary of the market potential and research needs of that technology.

The reinforced wood technologies were evaluated in consultation with industry representatives and researchers. The evaluation considered performance, applicability, availability, and competiveness of the technologies. The results are then prioritized and summarized in Chapter 5. The top five of those selected in priority list were chosen for further discussion in the Chapter 6.

Chapter 6 contains a summary of the findings and conclusions. Recommendations for future work on the top five ranked engineered wood products or technologies are also presented. Work plans outlining the research and development steps which will be necessary to facilitate the introduction of those potential technologies in Alberta and their eventual commercialization are included.

2.0 REINFORCED WOOD COMPONENTS

2.1 GENERAL

Wood structural components, such as beams and columns, could benefit from reinforcement by enhancing their mechanical properties and durability, and reducing maintenance. The idea of reinforcing timber is not new and attempts to reinforce wood components have been successful in the laboratory (3). There are patents on many varieties of reinforced wood and wood base materials. Most of these ideas, however, have not been developed commercially. The main reason is economics, since costly additional manufacturing steps are usually required for reinforced wood components. This is not to say that the reinforced wood components are never used commercially or there are no future prospects for this technology.

This chapter focuses on the reinforced timber including glulam timber. (Wood composites, such as particleboard, parallel laminated veneer, and parallel strand lumber, which are used rather synonymously with reconstituted wood will be covered in the next chapter.) This chapter reviews the past research in this area, discusses reinforcing materials, theory and analysis, and fabrication techniques. The prospects for these products and the future research needed to ensure their development are also explored.

2.2 THEORY AND ANALYSIS

In the design of any structures, the safe working and ultimate stresses must not be exceeded and deformation must be limited. Defects such as knots which cause large variation in the mechanical properties of solid wood plus the comparatively low modulus of elasticity of wood itself are the major detriments to the use of wood as a structural element. The use of reinforced wood components is aimed at overcoming these problems by increasing the stiffness and reducing the effect of defects in the wood. Often it is also desirable to enhance the strength, appearance, and durability of the wood.

Since most reinforcements are compatible with wood, the elastic properties of the reinforced members can be predicted on the basis of the elastic properties of component materials. By reducing the strength variability and increasing the stiffness of the reinforced wood members use of the ultimate strength design method becomes possible (39). Design methods similar to concrete and steel design, which are familiar to engineers, can be used to predict the ultimate strength of the members. This will increase the acceptance of wood structures by engineers.

Although wood is compatible with most forms of conventional reinforcement, an adequate shear bond must be provided between any reinforcement and the wood either by bonding, nailing or other fastening to ensure satisfactory performance. The efficiency of the shear bond of any reinforced wood component is usually determined by tests. The fabrication of a mechanical connection between reinforcement and wood is usually straightforward. The preparation of a bonded composite is more difficult especially when metals are used (40). The handling of metal pieces and preparation of the surface condition of metal do not allow flexibility for fabrication adjustment. Fiberglass reinforcements eliminate the need for special surface preparations and are easier to handle during fabrication. Nevertheless, the fabrication requires an additional cost-increasing step in the laminating process.

2.3 REINFORCING MATERIALS

Wood is compatible with various types of reinforcing material. Steel or aluminum plates, bars, rods, and strips, prestressed or non-prestressed, have been used in reinforcing wood components. Fiberglass, plastic and steel wire are other popular reinforcing materials. Regardless of the materials chosen, adequate shear transfer between the wood and reinforcing materials is critical to the strain compatibility of the components.

Metal Reinforcement

Steel is the most popular metal reinforcement as it is three times stiffer than aluminum. Only three papers (7, 8, 9) reported the use of aluminum plates as reinforcement for wood beams. Both horizontal and vertical orientation of the aluminum plates have been used to increase strength or stiffness, and reduce variability of the beams.

Steel reinforced timber dates back to the 1840s and some patents exist from 1920s (3). Wood components (mainly beams) are normally reinforced by steel plates, bars, rods, or strips either in vertical or in horizontal laminations with solid wood planks. The reinforcing steel can be either prestressed or non-prestressed.

Flitch beams (10) are beams consisting of vertical laminations of wood planks and reinforcing steel plates and are commonly jointed by nailing or mechanical fastening, as shown in Fig. 1 (page 15). This is the only kind of reinforced beam which has been discussed in design specifications (11, 12). The advantages of the flitch beam are that it is easily fabricated, readily handled and can be mass-produced. But technically it is not the most efficient use of the steel plate in flexure and produces no change for the wood in the strength and failure modes. Nevertheless, shear resistance of flitch beams is increased substantially due to the use of a metal web.

As opposed to flitch beams, horizontal reinforcing steels are placed on the top and bottom of beams, as shown in Fig. 2 (page 15), to improve the performance of wooden beams (13). The reinforcement increases both strength and stiffness of the beams and substantially reduces the performance variability of reinforced members. Hoyle (14) reinforced and connected a vertically laminated wood beam (Steelam) with a pair of toothed steel plates at the interface as shown in Fig. 3 (page 16). The mechanical connections were not loosened by repeated loading in the elastic range, and increases in stiffness were reported. The basic problems with horizontal reinforced beams are their handling and fabrication; consequently, they have never been developed commercially.

Another method of reinforcing wood beams is the use of prestressed steel reinforcement. Horizontally laminated wood beams were prestressed by post-tensioning high strength steel strands in the tension zone of the beams (15, 16). This method of prestressing increases the ultimate strength of the beams but produces no change in stiffness when compared with similar unreinforced beams. Limited data from four prestressed wood beams showed no loss in the prestressing force in eight years (17). Peterson (18) bonded prestressed steel plate to the tension side of laminated beams and produced significant increases in bending strength and stiffness. Again, economics currently prohibits the further development of the technique.

Coleman and Hurst (19) reinforced timber members only in critical areas of continuous structures with light gauge steel. Two types of local reinforcement, as shown in Fig. 4 (page 16), were used to resist high horizontal shear stress and high bending moment, respectively. The local reinforcement was found to be as effective as total reinforcement of timber beams. Vincent and Gopu (20) proposed a design method for radial reinforcement in pitch-cambered glulam beams. Radial reinforcement of lag bolts or rebars embedded in epoxy filled holes was provided in the central curved portion of pitch-cambered glulam beams. A significant reduction in the wood fiber radial tension stresses resulted from this reinforcement. This technique has been used to repair pitch-cambered glulam beams (21).

Other metal reinforced products which have been used extensively are metal-wood laminates. While virtually any combination of metal and wood can be produced, the most commonly used materials are steel and aluminum faces and plywood cores. Metal-wood laminates are used for a wide range of applications, including truck and trailer side panels; railway car interiors, bulkheads and doors; kitchen cabinets; and architectural applications of all kinds (22). Due to the cost, however, the products are used mainly for special functions or architectural purposes rather for structural performance.

Fiber Reinforcement

Fiberglass, graphite fibers, and steel fibers have all been used successfully to reinforce wood components. Rowlands, et al. (23) evaluated the feasibility of producing high performance reinforced wood components by testing ten adhesives (epoxies, resorcinol formaldehyde, phenol resorcinol, formaldehydes, isocyanates and a phenol-formaldehyde) and numerous types of synthetic fiber reinforcement (undirectional and cross-woven glass, graphite, and Kevlar). Results demonstrated that adding fiber reinforcement increased strength and stiffness. Glassfiber was found to be technically and economically superior to other synthetic fibers as a wood reinforcement.

Researchers have investigated the use of fiberglass in reinforced wood products for years. Wangaard (24) and Biblis (25) both reinforced various species of wood by applying undirectional strands impregnated with epoxy resin to the beam surfaces. Reinforcing laminated beams with fiberglass were also examined by Thenkston (26). He considered both a water base adhesive and an epoxy resin. The types of fiberglass mats examined were rovings, woven rovings, cloth mats, and chopped strand mats. Undirectional non-woven roving mats were found to be most suitable, but water based adhesive was rejected due to poor performance. Fiberglass reinforced plastics have been used to reinforce transmission poles (27). This reinforcing not only increased the poles' strength and stiffness but also enhanced their resistance to deterioration while improving appearance.

Fiberglass impregnated with phenol resorcinol formaldehyde has been used to reinforce impressed finger joints (28). The tension and bending strength of the joints were increased 10% to 40% over unreinforced joints. Butt joints in parallel laminated wood tension members have also been reinforced with a graphite-epoxy composite (29) with a 30% increase in tensile strength of the members.

The American Plywood Association (30, 31, 32) performed a series of tests on plywood overlaid with fiberglass reinforced plastic. Strength, stiffness and impact resistance were enhanced by all types of fiberglass used. The reinforced boards were quite durable, easily maintained and repaired. These boards have had extensive use in cargo shipping containers, railroad cars, and truck vans. Bulleit (33) applied a fiberglass reinforced plastic to the surfaces of flakeboard. Again, both higher strength and stiffness were reported.

Krueger and his associates have examined the reinforcing of wood with a composite of epoxy resin and woven steel fiber (steel wire) (34, 35, 36). The beams were reinforced by removing appropriate sections in tension and replacing them with the epoxy-steel composite. Based on the results of beam tests and analyses, an ultimate strength design method was developed for tension-reinforced timber beams. This composite has not been developed commercially to this date.

Plastic Reinforcement

Plastic has long been used as reinforcement in wood products with parquet flooring being a major commercial example. Other commercial items include sporting goods, musical instruments, office equipment, and kitchen supplies. Plastic is known for its good abrasion resistance, dimensional stability and homogeneity of compressional properties (37). Plastic weighs much less than other reinforcing materials, i.e. fiberglass, steel, or aluminum.

Plastic reinforcement normally starts with the impregnation of wood with vinyl monomers, followed by free radical bulk polymerization with a Co-60 source (38). In most cases, the polymer is located in the cell lumen and does not enter the wood cell wall. By adding bulk vinyl polymers to the void spaces in wood, compression strength, hardness, and abrasion resistance are greatly improved.

Plastic reinforcement is only used for protection of the wood or to reduce product variability. To date, there has been no commercial development of plastic impregnated wood structural members. The reason is that plastics generally have a modulus of elasticity less than 15 x 10^3 MPa and strengths in the order of that of wood. Therefore, unless other high performance reinforcing materials, such as fiberglass, are added, the wood-plastic combinations produced by the present method may not be recommended for applications where increased strength is desired. Further discussion on plastic-wood composites will be made in Chapter 3.

2.4 POTENTIAL AND RESEARCH NEEDED

The major advantages of reinforced wood components are increased strength and stiffness and reduced variability. All of this notwithstanding, most of reinforced wood products have never been used commercially. There are three possible reasons: (1) the material used to reinforce the wood was not commonly used in building construction; (2) the reinforcing material was too expensive; and (3) an additional and costly fabrication step was needed. One or more of these would make a reinforced wood member uneconomical or unappealing.

The possibility of using reinforced timber or reinforced laminated timber on a commercial basis seems unlikely since all methods have proven too costly. Localized reinforced wood members, such as localized reinforcement at the critical sections of a member (Fig. 4, page 16), radial reinforcement in pitch-chambered glulam beams (20), and joint reinforcement in laminated timber or in parallel laminated veneer (28, 29) appear to be viable possibilities. Only minimal work has been done in the area of localized reinforcement and research is necessary to determine if it is a viable method of reinforcing wood components.

Surface reinforced plywood, such as metal-wood laminate or plywood overlaid with fiberglass reinforced plastic will most likely continue to be used in industrial packaging and the transportation industry. The increased use of particleboard and flakeboard cores would seem to be a natural extension of these two product lines. It would also seem the use of low quality particleboard with a surface reinforcement in structural application may be a possibility. Using less expensive particleboard with surface reinforcement might prove to be cost effective. Furthermore, the surface layers could act as moisture barriers which might improve the creep behaviour of the core. Surface-reinforced panels and reinforced composite panels will be discussed further in the next chapter.

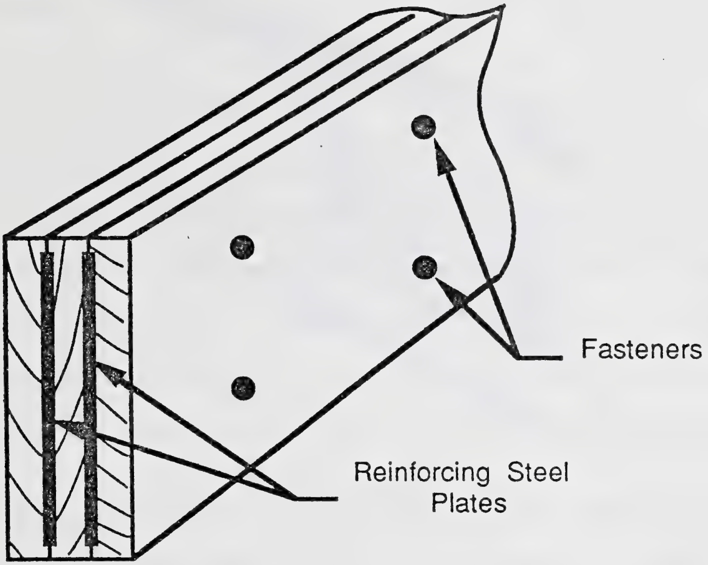


Fig. 1 Vertical Reinforced Timber Beam

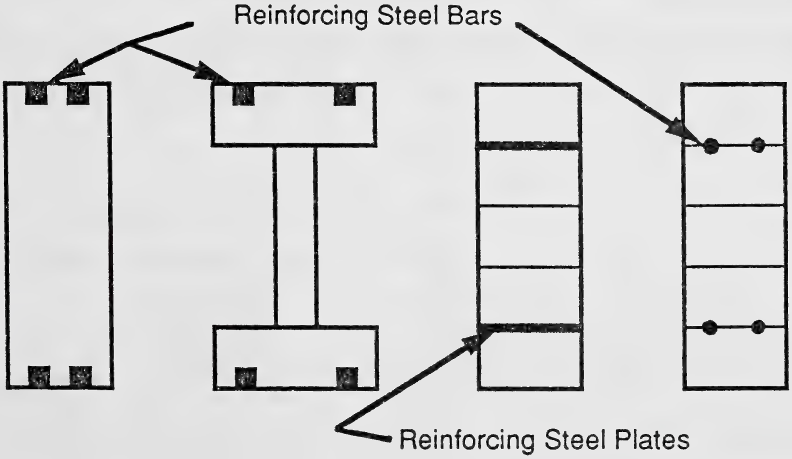


Fig. 2 Horizontal Reinforced Timber Beams

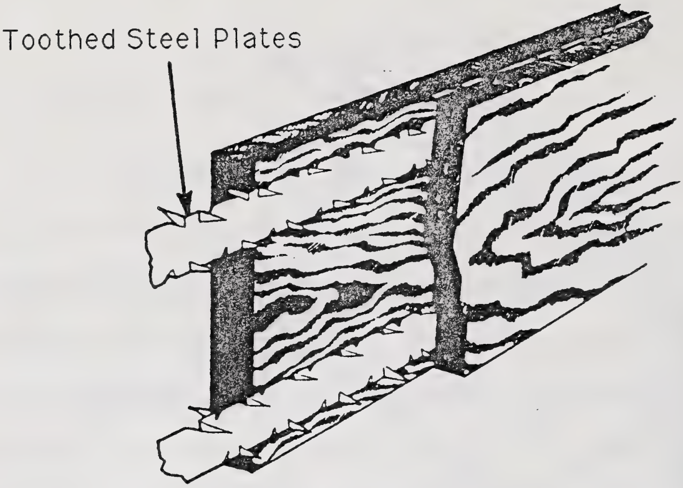


Fig. 3 Steelam Beam

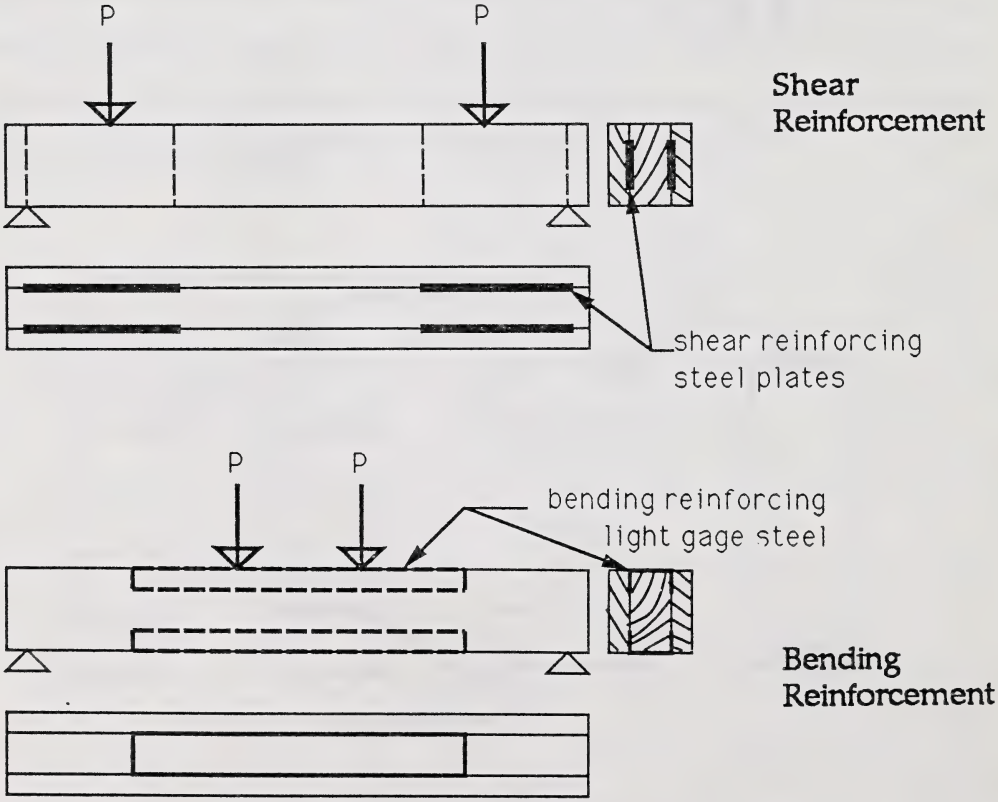


Fig. 4 Local Reinforced Beams

3.0 WOOD COMPOSITES

3.1 General

The most significant progress in wood product development over the past two decades has been in the field of wood composites. Acceptance of wood composite products, such as waferboards and oriented strandboards, can be seen throughout the North American building industry. This is attributed to the increased demand for wood and the resulting pressure for the better management and more efficient use of our shrinking forest resources.

The concept behind wood composite is to use low grade logs, mill residues or the "useless weed woods", such as aspens, in the form of veneers, particles, flakes, strands, or chips as raw materials, then reconstitute them as a bonded composite. This yields high quality wood products from the wood resources which were previously viewed as having little or no commercial value. Further, there is less waste compared with conventional methods of converting wood into lumber. Composite wood technology offers the potential flexibility of converting wood into a variety of high value composite wood products. The process also facilitates the incorporation of non-wood materials, such as concrete, steel, fiberglass, or plastic into the wood composites to enhance their performances.

The terms "wood composites" and "wood composite products" used in this chapter denote anything formed by breaking the tree into small pieces and reforming those pieces in a bonding medium to form a new product or material. Nonwood materials might be laminated or integrated with the wood to improve composite performance. Built-up members, such as I-beams and box beams, and built-up structural systems will be covered in the next chapter.

3.2 WOOD/COMPOSITE MATERIALS

There are three input choices which must be considered for wood composites: wood species, particle sizes, and, most importantly, adhesive (41).

Urea-formaldehyde adhesives are the most commonly used resins for conventional particle board manufacture in North America and Europe because of their relatively low cost and short curing times. This type of resin is intended for interior use only. Phenol-formaldehyde resin, the same basic resin used for plywood, is used for most particleboards intended for exterior or structural use. A relatively new but potentially important binder is isocyanate (42) which is now used in some plants in Alberta. Although expensive, it can be used in smaller quantities than phenolic resins. Since this binder contains no water, as do both ureas and phenolics, there is a further cost saving related to reduced drying time.

Portland cement is another material which has been used to produce wood-cement composite panels. Portland cement mixed with wood flakes or wood excelsior in various ratios has been studied and the products have been used commercially for their high fire, insect, and fungal resistance, in addition to good weatherability and acoustic insulation properties.

Wood/plastic combinations present another possibility for composites. Wood and plastic are combined and the plastic melts, but each component remains as a distinct separate phase. These products are light in weight, control biodegradability, and exhibit improved acoustical, impact, and heat reformability properties. Furthermore, the use of low-cost recycled plastics would make the products more competitive and environmentally attractive.

The other reinforcing materials and techniques discussed in the previous chapter, such as steel, synthetic fiber, and localized reinforcement, can also be used in the wood composite products provided they are cost effective.

3.3 WOOD COMPOSITE PRODUCTS

The wood composite products listed here are limited to the more recent innovative ones. Conventional products such as plywood will not be discussed here. The combinations of these new products and/or conventional lumber will be covered in the next chapter.

Particleboards

Wood particleboards are panel products which are manufactured by heating and compressing small particles of wood that have been sprayed or dusted with a binding resin (adhesive) (43). The wood particles can come from almost any type of wood, whether whole logs or the residues from mills. Phenol-formaldehyde resin is used for most particleboard production that is intended for exterior or structural applications. In Europe, urea-formaldehyde has been widely used in producing particleboards for construction of home floors and interior wall surfaces. In North America, however, such boards are considered to be suitable only for furniture manufacture but not for structural subflooring or sheathing in residential construction. As noted, isocyanate binder is also gaining acceptance in Canada. Intensive research into binder development will continue due to the rising costs and uncertainty of natural gas and oil supplies from which the binders are manufactured (42).

The different types of particleboard used in construction are referred to variously as flakeboard, chipboard, waferboard or strandboard, depending upon the size and shape of the wood particle used (43). In some areas particleboard refers to those boards made with the finest of particles, while the boards made with flakes or wafers are called composite panels. These boards not only differ visually but are also quite different in terms of their strength, durability and dimensional stability. Most particleboards produced in Canada are from whole logs (mostly pulpwood) (44). When producing particles from this source, it is possible to control the size and shape of the wafers or flakes. Waferboard and oriented strandboard are two products requiring the particles be cut from whole logs. In the United States, most particleboards are produced from residues (shavings, sawdust, or chips). The American National Standards for particleboard (45) categorizes it under three variables: board density, quality class, and resin type. The Canadian standards (46) recognize 11 grades of particleboard, which are differentiated principally on the basis of physical properties. Performance standards of the American Plywood Association (47) apply only to particleboards intended for structural applications.

In the last few years, particleboards, especially waferboard and oriented strandboard (OSB), have gained acceptance as structural panels in building construction in Alberta. OSB is composed of wood flakes or strands that are similar to wafers in waferboard but narrower, and thus can be aligned. In OSB the strands are oriented in layers that are perpendicular to each other as in plywood construction. Flake alignment gives the panel superior bending strength, stiffness and necessary dimensional stability. The difference between OSB and waferboard is not as distinct as it was in the early 1980's because many waferboard producers are now cutting wafers with some length-width difference and aligning these wafers to some extent in the panel.

With a dwindling supply of mature softwood lumber and abundant fast-growing aspens in Alberta, continuous growth of the particleboard industry is predictable. Nevertheless, Singh et al. (48) in their economic study of particleboard in Canada indicated the market for particleboard is not very sensitive to its own price but rather is very sensitive to variations in the price of plywood. Since particleboard is generally priced about 30% lower than softwood plywood, it is regarded as a substitute for plywood, which traditionally had a good public image. The study concluded that unless there is a strong R & D effort to substantially improve the quality of particleboard, any hope of seeing it replaces plywood will probably not be realized. In fact, particleboard may remain only a lower quality, lower priced product filling the gaps left by plywood in the panel market. Furthermore, the expected rate of growth in particleboard production forecasts a gross oversupply in the Canadian sheathing market, thus forcing a search for broader markets. This could lead to development of greater variety in product appearance, thus moving particleboard into the residential cladding and interior decoration markets. These possibilities will be further explored in "Composite Panels" (page 24).

Fiberboards

Different terms have been used to identify the various panel products made from wood fibers and intended primarily for building construction, and furniture or cabinet manufacture. The American Society for Testing Materials definitions (49) refer to them as "fibrous-felted boards", divided further into "structural insulating boards" (less that 31 lb/ft^3) and "hardboards" (greater than 31 lb/ft^3). Fibrous-felted boards differ from particleboards in that refined or partially refined lignocellulosic fibers are used in the manufacturing processes rather than the discrete particles such as one finds in waferboard and oriented strandboard. Wood fiber can be obtained from a multitude of resources besides the traditional pulpwood. Sawmill, logging, and pulpmill wastes, as well as veneer scrap have all been used as fiber sources.

Low density fiberboard (less that 31 lb/ft^3) is mainly used as insulating boards. Hardboards are classified into two groups: (i) medium-density hardboard (31 lb/ft^3 to 50 lb/ft^3) and (ii) high-density hardboard (greater than 50 lb/ft^3). They are used for siding, floor underlayment, concrete forms, wall panelling, etc. Small amounts of phenolic resins are normally used in the hardboards to add additional strength, even though most of the integrity of the boards is due to interlocking of fiber and hydrogen bonding (50). A more recent development is medium-density fiberboard (MDF), which combines the technologies of the hardboard and particleboard industries. MDF is manufactured from wood fibers combined with a synthetic resin, usually urea-formaldehyde, and is intended for interior use. It has replaced other products as a core material in the furniture industry (51).

Because of its low physical properties, the prospect for fiberboard as a structural panel is not good (51). Better performance may be achieved by using other high performance composite materials to design a better fiberboard microstructure (52). Nevertheless it is tough, smooth, and can be embossed; further, it consumes only one-tenth the energy of gypsum board (4). Fiberboards now offer the greatest potential for general-purpose housing interiors and embossed medium-density hardboards have been manufactured as siding panels (53).

Wood-Cement Panels

Portland cement has been used in several types of wood-based panels. The most important of these product is cement-bonded excelsior board (CEB) (54). The CEB is a porous low-density product which is used principally for acoustical ceiling panels in commercial and industrial buildings. CEB is about 1/4 to 1/3 wood by weight, the remainder being portland cement or other mineral binder. The density of CEB ranges from 20 to 25 lb/ft^3. The product is well suited to developing countries because it can be produced by very simple hand-forming methods using locally available materials.

Another wood-cement product is manufactured in a manner similar to conventional particleboard except portland cement is used as a binder (55). The density of the product ranges from 60 to 75 lb/ft^3. Most of these products are made in Europe and Asia, few in North America. Wood particles make up only 25% of the products by weight; thus, the higher cost of cement increases panel raw material costs.

Cement bonded panels have excellent resistance to fire, insects, fungus, and decay. They also have good weatherability and acoustic properties, but their strength and thermal insulation properties are modest (54). The primary difficulty of this product is high species selectivity (56). Many species of wood contain wood sugar or other extractives which retard or inhibit curing the cement. In addition, compared with plywood, its high density and the difficulty of cutting and fastening it may deter its growth in North America.

While exhibiting many excellent properties, reducing the cost and improving workability are essential if wood-cement particleboard is to become a widely used structural panel. The use of fly ash in wood-cement composites (57) and the possibilities of using wood-cement particleboards for high quality stress-skin panels (58) are two areas which might be worth further research especially in product and systems development.

Composite Panels

As noted, it is logical to combine or laminate wood products with other materials into various composite wood panels to take advantage of each product's strengths. The combinations and potentials are virtually unlimited. Various attempts have been made in the laboratory and in the market, such as particleboard laminated by fiberboard, particleboard skinned by metal or plastic, composite wood panel reinforced by fiberglass skins, and softwood veneered with particleboard or fiberboard. Considerable effort was made by the American Plywood Association to produce a composite panel consisting of a particleboard core covered with softwood veneers (59, 60, 61). These veneered panels both looked and performed very much like plywood. Unfortunately, poor market conditions closed most of the veneer-particleboard composite plants in the United States.

The prospects for composite panels are good, but as with many other successful new products, it requires market investigation in addition to research/development programs. Public acceptance depends on the price competitiveness and functional versatility of the new products. Failure of the veneered-particleboard in the market was due to its limitation of function to that of replacing plywood which has traditionally enjoyed good public acceptance. Further, the price of the veneered panels was not as competitive as waferboard or OSB. New composite panels should be performance-driven and multi-functional. The success of fiberglass/particleboard composite panels in the cargo and trailer industry is attributed to their ease of maintenance and repair, cost competitiveness, and higher structural performance which eliminates the need for space-robbing posts and interior liners (62). Due to the oversupply of particleboard in the Canadian sheathing market, we need to develop a broader market for it. Laminating the particleboard with hardboard or textured fiberboard for housing interiors appears to be one of the options. Particleboard with wood-cement composite skins can be used as residential siding or as concrete forms. Some research has been done to improve the physical properties of a dry-process hardboard through internal reinforcement with continuous glassfibers (63, 64). The product retains the advantages of fiberboard, but with improved structural properties. However, its high manufacture cost many be a deterrent to its further development.

Composite Lumber

The wood industry is increasingly unable to reliably supply straight studs or joists due to diminishing mature log size. This problem has led to the use of steel-stud partitions in small scale commercial/industrial construction. Composite lumber, however, has a promising future with a consistency of quality, a knot-free, grain-free uniformity and a tailored utility, that solid wood lacks. The techniques allow production of large sizes of lumber (2 x 8 or 2 x 10) from small, low grade logs. Furthermore, composite lumber compares favorably with solid lumber in both uniformity of quality and straightness. The quality of lumber is determined by the raw material which nature varies while the quality of composite lumber is dependent upon the manufacturing process which man controls. Several composite lumber products have either been developed or are on the market. While the major disadvantage of these products currently is their relatively high cost, it is likely that with a shrinking forest resource and improving manufacturing techniques the use of composite lumber will increase (65).

Today's products include parallel laminated veneer, parallel strand lumber and Com-ply lumber (65). Most of these products are used as substitutes for larger structural softwood lumber and in applications where uniform strength is essential.

Parallel laminated veneer (PLV) is processed in a manner similar to plywood, but consists only of parallel laminations (66). Also called laminated veneer lumber (LVL), veneers of PLV are rotary peeled, dried, spread with adhesive, laminated in the desired configuration, pressed either in conventional plywood presses or on a continuous or step basis, then cut to width. Various commercial products, such as MICRO=LAM (67), Kertowood (68), Press-Lam (69, 70), and Lamineer LVL (71), are produced based on various processing techniques. Fiberglass has been used in the laboratory to reinforce PLV and produce high performance lumber (72). The fiberglass is sandwiched between veneers (73) or is placed locally at veneer joints to enhance performance (74, 75). These products can be used where high performance and uniform quality are required.

Parallel strand lumber (PSL) is made from long strands of wood and is extruded with resin into various cross sections and widths. Parallam is a commercial product in this area. PSL is a logical extension of particleboard technology to maximize wood resources, while PLV builds on advances in the plywood industry to utilize small-diameter logs. Fiberglass has also been used to reinforce PSL along its length because of its relatively weak flexural bending strength compared with PLV (76). Because PSL can be made from Alberta's abundant aspens, it might be the next potential product used in the Province's residential construction industry due to short supply of alternate high quality of lumber.

Another interesting product, Com-ply lumber, is made from a combination of veneer and particleboard (77). This product, developed by USDA Forest Service is produced by parallel-laminating veneer to the edges of strips of 1 1/2" thick particleboard. The product can be produced in any depth desired and thus can be made to match common lumber sizes (i.e. 2 x 4, 2 x 6, or 2 x 8). Com-ply lumber has been used as studs and joists of the floor system in an experimental home (78). The product performed satisfactorily and was more dimensionally stable and warp-free than solid lumber.

Shaped Particle Wood Products

The major reason for the success of the sheet steel industry was its ability to use less material (thus was cheaper) than hot-rolled steel while performing the same or even more functions. Sheet steel can be tailored to various shapes to take advantage of its physical properties and/or to serve specific purposes. Wood composites offer the same advantage over conventional solid wood or plywood. Since this concept is still in its infancy, strong R & D is needed before these benefits can be realized.

The Alberta Research Council is at the forefront in this area. Various shapes of corrugated waferboard have been successfully manufactured and tested at the Alberta Research Council, Forest Products Laboratory (79). Corrugated waferboard evolved from particleboard by introducing a wave shape into the product to markedly increase its strength and stiffness. Being an inexpensive wood composite with a performance comparable to other corrugated materials, it is expected to open new markets. Further R & D and marketing studies are needed to encourage commercial acceptance of corrugated waferboard.

Geimer and Lehmann (80) used several forming methods in constructing I-beams of reconstituted wood particles. Shaped molds and standard particleboard pressing techniques were used. A low bulk density fibrous material was used in the web portion, and aligned flakes with high bulk density for the flanges. The bending stiffness of the beam was comparable to that of a solid lumber beam of equal weight, but its bending strength was only half that of a lumber beam. Physical properties related strongly to beam configuration and indicated that, with improved design and construction techniques, beams could be made to suit a variety of structural applications. This technique is specially attractive when used in standardization and mass production.

Others - In addition to the above innovative products there are unlimited opportunities for combining wood with nonwood materials (81). Wood/biomass and wood/plastic are two of the most promising possibilities.

A cooperative research project by the Alberta Research Council and University of Alberta is underway to investigate the feasibility of using flax as a panel material. Another logical step is the combination of non-wood lignocellulosics, such as agricultural residues and biomass fibers, with wood to produce lower-cost composites. Youngquist and Rowell (81) presented data on improving the properties of many different types of lignocellulosics through the simple process of acetylation noting a 60% reduction in equilibrium moisture content (EMC) at about 20% bonded acetyl. Acetylation greatly decreases moisture absorption and significantly improves composites' resistance to biological attack and ultraviolet degradation. This is an example of producing high performance wood/biomass composites by advanced technology.

Wood/plastic composites are particularly attractive because of the abundance of plastic waste and the slow degradation of the resulting products. Wood/plastic products are also light weight and demonstrate improved acoustical, impact, and heat reformability properties (82). Modern blending equipment permits proper mixing of the plastic and wood components which can then be extruded or injection-molded into a number of configurations and shaped sections. The one outstanding problem which merits continuing research is the less than exceptional bond between the two dissimilar materials (82).

3.4 POTENTIAL AND RESEARCH NEEDED

Economic pressure, environmental realities, and social policies will push forest industry evolution toward utilization of all species and sizes, even the smallest trees, and demand their highest value utilization.

Structural wood composite products which can use any tree, and all of it, become a logical choice. Research efforts to improve production processes and performance levels offer opportunities to utilize wood which was previously discarded, thus extending the current supplies without additional harvesting. This explains recent industry efforts to develop composite wood products. Their public acceptance is good, but the products are still regarded as substitutes for solid wood and plywood. Research to improve the structural performance, development to enhance the versatility, and marketing to improve the public image are keys to the future success of the composite wood products. The following sections evaluate the short- and long-term potential of each previously discussed product, and address the research that is needed to foster their further development and subsequent commercialization.

Particleboards

It is expected that the particleboard industry will continue to grow in the short-term. The increased demand being experienced in the market place, however, may be due to the recent influx of a number of new firms, which have created a price war. Consequently, either a decline in the quality of the product or an increase of price must eventually occur. Either way, the long-term competitiveness of particleboard versus plywood will decrease. However, maintaining good quality control in particleboard production could help improve its otherwise declining image.

Marketing studies and public awareness of environmental issues are essential to the continued success of the product. Establishing a rigorous grading system through the Canadian Standards Association will increase public confidence in the product; improving the production process will enhance the cost advantages of the product. Large sheets allow faster and higher quality construction of floor decks, roof sheathing and wall sheathing (83). Production of thicker particleboards with resulting longer span capability can increase the joist spacing, ultimately reducing the number of joists required in a project. A search for broader markets will be inevitable due to an oversupply of the product. Seamless large-sheet fiberboard surfaced particleboard may be able to compete with gypsum drywall as interior panelling. Continuous-press large-sheet particleboard complete with insulation might be prefabricated as seamless stress-skin panels for use in small scale commercial/industrial construction. Fiberboard/particleboard composites, when used in prefabrication construction, can produce a whole-wall siding and significantly speed up construction.

Fiberboards

Fiberboards present another exciting opportunity for new wood products. The success of medium-density fiberboard (MDF) in the furniture industry tells the story of fiberboards: it offers toughness, homogeneity, smoothness, hardness, decorability, moldability, and seamlessness. This implies a greater potential for fiberboard as a general-purpose housing interior finish. Fiberboard can also be laminated with particleboard or reinforced with synthetic fibers to enhance its physical properties. Since fiberboard can be molded into textured shapes, it might recapture the residential siding market that lumber lost not too long ago. Combined with particleboard and prefabrication techniques, whole-wall sidings with surface texture and exterior finish are but one of the unlimited possibilities. Fiberboards exhibit many environmental advantages: they require only 1/10 the energy consumed by gypsum board, and they use virtually any fiber resources (even recycled paper). Consequently, they potentially represent one significant line of advance for future forest products.

Wood-Cement Panels

Porous low-density wood-cement panels will continue to be used principally for acoustical ceiling panels in commercial and industrial buildings. As for structural panelling, its high cost and heavy weight, compared to particleboard, may be a deterrent to its growth (especially in forest-rich Alberta). With improved workability and reduced cost, which can be achieved by adding other nonorganic binders such as fly ash, wood-cement panels might prove to be a viable product. Innovative structural systems, such as using wood-cement panels as the outer skin of a stress-skin panel, might be cost effective concepts. However, more research is needed in product and system development plus market and price studies before these products can be exploited.

Composite Panels

Although the use of composite panels is not new, few have been used in building construction due to their high cost. With the development of lower cost composite wood panels, they present a brand new challenge to researchers and engineers. In addition to functional versatility, price competitiveness will be a key factor to the future success of composite panels. Consequently, it is essential to conduct thorough economic studies before developing any new composite panel products.

Composite Lumber

The intensive research and development into composite lumber is being driven by diminishing mature log sizes around the world. Again, however, their relatively higher cost compared with conventional lumber might limit product acceptance. Parallel strand lumber might be the next product after OSB to be used in housing construction in Alberta due to the ample supply of hardwood in the province. Parallel laminated veneer can meet the market demand for higher quality, large sizes lumber. Com-ply lumber may also prove to be cost effective, especially if high grade 2 x 1 or 2 x 2 lumber can be used to replace the PLV in Com-ply lumber. Alternatively PLV might be used as the tension lamination in high performance glue-laminated timber. Regardless of the product or process eventually chosen, it is expected that the use of composite lumber will increase as the supply of high quality lumber decreases.

Shaped Particle Wood Products

The great flexibility of composite wood technology is best demonstrated by shaped particle wood products which can be molded into various profiles to take the fullest advantages of wood's unique physical properties. The products can be standardized in shape and size with existing manufacturing processes, but innovative processes and capital investments will be necessary for the products to become cost effective. Although the potential of this technology is unlimited, strong R & D is needed before its technical benefits can be realized. Strong marketing will be needed to ensure public acceptance.

Others

It is said the 90's is the decade of environmental awareness. Use of renewable and recycled materials is one of the major parts of this movement. Wood/biomass and wood/plastic present two of the most exciting challenges. Preliminary research results in these areas suggest a promising future, but more research is needed before we can enjoy the environmental benefits of the technologies.

Research Needs

The research needed to facilitate continued development of composite wood products includes better adhesives, processes, and further investigations of actual performance.

The focus of adhesive research in the years ahead shall include: deriving adhesives from renewable resources, developing adhesives for special uses, developing methods to reduce and possibly eliminate formaldehyde emissions from bonded wood products, and studying the durability and weatherability of alternative wood adhesive systems. Given its market size, coupled with rising costs and uncertain gas and oil supplies, binder development and research will continue to be the focus of intensive adhesive research.

Research is needed into the manufacturing process to study the suitability of various species, develop peeling and flaking techniques, investigate quantities and means of resin application, and develop innovative pressing technologies. The emphasis for the processing innovations should be to decrease energy consumption while improving product quality. Manufacturing automation will prove to be a "must" in this highly cost competitive market.

Creep deflection may be the most critical of all the structural concerns for composite wood products. Particleboards, though in use for more than 40 years, have little history of performance under load. The need for creep research on composite wood products has received great attention in the last 15 years. But more research is needed especially into applications where the products are exposed to moisture cycling conditions.

The short-term mechanical properties of wood composite present a simpler and brighter picture. However, performance criteria establishment and test method rationalization are slow processes and hence became stumbling blocks to the evolution of wood composites. The performance criteria are sometimes nonexistent, or at best tenuous, and test methods are often not suitable for the new products they are being applied to. The development of performance-based standards is the only way to maintain the momentum of this dynamic area, but those standards must be based on broad and rigorous full-scale field testing to ensure that they meet the actual loads and conditions found under field conditions. Other technical research, into such areas as fire retardants and preservative treatments on composite wood products, are needed before these products can be used widely.

In addition to research required into the mechanical performance of the composite wood products, engineering data is required before we can take full advantage of these products' unique attributes in actual practice. Joints may prove to be the biggest obstacle to the use of new composite wood products. Most of the existing literature on joints is limited to solid wood, plywood and glulam beams, while very little information is available on the behaviour and strength of wood composite joints. As an example, consider the corrugated waferboard developed at the Alberta Research Council. Without information on joints and joining details, there is little potential for it to be used by designers; consequently there will be very limited demand for the product.

4.0 BUILT-UP MEMBERS AND STRUCTURAL SYSTEMS

4.1 GENERAL

A light wood-frame building is a complex, highly indeterminate structural system made of interacting two-dimensional subassemblies, such as foundations, floors, walls, and roofs. In each subassembly, structural members (joists, beams and columns) and sheathing materials are connected together by various types of fasteners, glue, and steel connectors (84). Solid lumber or glulam timber is normally used for joists, beams, and columns, while plywood is used for sheathing materials. The design procedures for wood-frame buildings treat the subassemblies as acting independently of the others (85). Most sheathing materials are regarded as non-structural elements that contribute nothing to the assembly's strength and stiffness. This produces safe but very conservative structures.

Light wood-frame buildings have performed satisfactorily in the past. However, because of escalating costs for larger sizes of lumber, labor, and energy, current practices in the wood-frame construction must be changed to be competitive with other construction methods and materials. Modified structural members, requiring less and smaller structural lumber, and material efficient modular subassemblies, are two current trends in wood-frame construction. Wood I-beams and pre-fabricated stressed skin panels with integral insulation are two examples in this new technology.

In the next two sections, built-up members and structural systems (subassemblies) will be evaluated for their performance, availability, applicability and economy. The market potential and research needs of each product are outlined in section 4.4.

4.2 BUILT-UP MEMBERS

Glue-laminated timber is the first and the most successful example of built-up members using predetermined arrangements of various grades of small dimensional lumber to produce larger and better grade wood members. Nevertheless, the lack of higher grade lumber for the tension laminations in glulam timber and the competitiveness of the construction market calls for other alternatives. Researchers have estimated that a 50% reduction in wood use can be achieved by using built-up wood structural shapes, such as I- or Box-beams (86). Furthermore, small dimensional lumber can be fully utilized in these types of production. Current CSA standard CAN 086.1-M89 (85) permits the use of built-up members both in compression and bending when the appropriate engineering design and lumber or panel grades are used. Since most residential buildings are currently constructed as pre-engineered buildings, few built-up members are being used. Improved prefabrication technology or easier field fabrication are necessary if built-up members are to be successful.

Wood I-Beams

Prefabricated wood I-beams represent an efficient use of material for structural applications. The I-beams are built-up members that are manufactured using sawn or wood composite lumber flanges and structural panel webs. The flanges and webs are bonded together with exterior-type exposure adhesives, forming an "I" cross-sectional shape. Used primarily as floor and roof joists (87), I-beams have also been used as support beams, garage door headers, and framing components.

Most I-beams use plywood webs and design standards and methods for these components are available (85, 88). Although particleboard and fiberboard panels are used, the lack of design values preclude these materials from being fully utilized as primary structural members. The hesitation to assign design values is attributed to a lack of information on material properties, especially time-dependent behavior such as creep. Furthermore, the environmental durability of these materials is often questioned. Particleboard is a rational alternative as the web material in Alberta, but more research is needed into its performance in the I-beams, such as time dependent, environmental and flake orientation effects (94). Therefore, a comprehensive understanding of the properties of wood composite panels is essential before they can be fully exploited (89).

Recently, wood I-beams have gained popularity in small scale commercial/industrial construction due to their competitive price and satisfactory performance. However, the wood I-beam is a complex assemblage of orthotropic and anisotropic materials. The static strength of I-beams is influenced by the strength and stiffness of the composition materials, adhesive strength and stiffness, web opening, and connection details (90). Web buckling, lateral-torsional buckling, and stiffener and bracing requirements are also important design considerations (91). Furthermore, as with all wood-based materials, environment and load duration can significantly influence I-beam strength and stiffness, especially when wood composite lumber or panels are used (92, 93). Since I-beams are bonded into a system of wood components that produce a stiff and low mass element, the dynamic performance of I-beams is likely to be significantly different from that of sawn lumber. Vibration must also be further investigated before I-beams are used more extensively in structural systems.

The I-beam's high degree of structural efficiency will contribute to its continued growth and increasing acceptance. However, although we know a great deal about the static performance of the product, we know much less about the long-term performance, dynamic behavior, and reliability of these components. .

Wood Box Beams

A wood box beam is another example of built-up shaped members that provide not only the material efficiency of I-beams but also structural stability and torsional rigidity (95). However, the wood box beams are more difficult and expensive to fabricate than the I-beams. Most of box beams used today are designed by engineers which makes the box beams uneconomical for most residential and small commercial projects. As with the I-beams, current Canadian standard CAN -086.1-M89 (85) permits only plywood panels as the web materials in box beams. Use of particleboards in the web and prefabricated technology in the manufacture process might prove to be economically feasible. More research and development is needed before the benefits of the box beams can be realized.

Composite Glulam Beams

With diminishing availability of high grade lumber, the stock of high grade wood for use in the tension lamination of glulam beams is shrinking daily. A possible method of replacing this stock is the use of high grade composite lumber (such as parallel laminated veneer) or reinforced tension lam. Bulleit et al. (96) replaced the wood tension lamination with reinforcing steel embedded in oriented flakeboard, as shown in Fig. 5 (page 49). Although the strength and stiffness of dry glulam beams showed a 30% increase, this advantage was negated by moisture cycling. This lack of reinforcing effect was attributed to reductions in the wood modulus of elasticity and loss of the flakeboard's internal bond strength caused by the increased moisture content.

Use of high grade composite lumber in the tension lamination seems a more feasible alternative. High performance and uniform quality of the composite lumber will simplify the quality control procedure at the production levels. It also requires no changes in the laminating procedure. Nevertheless, until the production cost of composite lumbers decreases or the supply of tension lam ceases, this technology might prove to be uneconomical.

Corrugated Waferboard (Waveboard) Webbed Beams

Although wood I-beams represent an efficient use of material, they are limited to certain depths. Otherwise, stiffeners are required to prevent local buckling of the web or web crippling. Replacing plywood or OSB web with waveboard, as shown in Fig. 6 (page 49), will increase the shear buckling strength and bearing strength of the web significantly thus allowing for deeper sections without stiffeners, creating a more economical product. Automated prefabrication processes will be needed to make these products competitive. More research and market study are required to explore this possibility.

Mechanical Connected Members

The shortage of large dimension solid-sawn lumber is increasing the need to develop new substitute products. However, one major impediment to consumer adoption of new products is their unfamiliarity with the materials used in that product. One possible solution to these conflicting positions is the use of smaller dimension lumber, connected with mechanical fasteners, such as metal plates or nails. Ease of fabrication and reliable performance are two essential factors which could enhance the success of the product. This differs from the reinforced wood components described in Chapter 2 as no reinforcing material is used.

Emanuel et al. (97) investigated the behavior of double 2 x 4 members laminated horizontally with metal plate connectors and compared the strength of the members to that of the glued-beams with the same overall dimension. They concluded that the metal plate connectors effectively transferred the interface shear between the two components to produce a highly efficient composite member.

Spliced, nail-laminated posts were studied by Winistorfer et al. (98). The 11 foot long posts with a 6 x 6 cross-section were fabricated by splicing and nail-laminating 2 x 6 sawn lumber. The effects of three splice variables, splice length, splice location, and the presence or absence of a reinforcing metal nail plate, on post stiffness and bending strength were studied. Increasing the splice length and adding a nail plate had significant effects on the ultimate strength and stiffness of the posts, while the location of the joint along the post showed little relative effect on stiffness and no effect on the ultimate strength.

Spaced compression member design outlined in the CAN-086.1-M89, Appendix A (85) is another application of this technology. Comprehensive research into mechanical connected members is needed in order to use the material efficiently and produce reliable products.

4.3 STRUCTURAL SYSTEMS

Structural systems are two-dimensional or three-dimensional structural subassemblies which are pre-assembled to perform in specific applications, such as floors, walls, and roofs. Prefabricated roof trusses are an example of this application. Structural systems are a logical extension of built-up members, making efficient use of materials and performing additional non-structural roles. Construction cost can be significantly reduced through systematic design and mass production. The possibilities and combinations of these structural systems are virtually unlimited. While the technology is especially suitable for exporting, the assemblies themselves are more difficult to transport and less flexible than conventional site-connected structural components.

Stressed Skin Panels

A stressed skin panel (SSP) is made of two primary components, the flanges and the webs. The flange component is often called a skin because it is usually made out of a thin sheet material. The skin and web are bonded together to form a composite unit (99). The panels are usually used as flexural members, but are suitable for walls, floors and roofs in various types of buildings. The panels can also act as shear diaphragms to resist in-plane forces, such as wind loads (100).

The 7S-3000 stressed skin panel patented by Seven S Structures Inc. in Alberta is manufactured with OSB skins and sizes up to 8' x 24'. The hollow cavities of the panel are injected with polyurethane insulation, which expands inside the panel and bonds to the OSB forming an air-tight vapor barrier (101).

The SSP provides simple and easy construction and can eliminate the use of roof trusses, joists etc. as found in conventional wood-frame construction. It is particularly useful for small scale commercial/industrial construction. However, since the panels are prefabricated in large sizes, they are not as easily transported nor as flexible as conventional residential wood frame construction.

Like many other composite members, the creep behavior of SSP requires further investigation before the product can be used confidently (102). This is especially true for the SSP since no joists or studs are used in the system. Additional research is needed to investigate the shear diaphragm strength of the SSP in order to take full advantage of these panels.

Truss-Framed Systems

The truss-framed system (TFS) combines floor, walls, and roof into a unitized frame for structural continuity from the foundation up to the ridge, as shown in Fig. 7 (page 50). The system was developed at the U.S. Forest Products Laboratory (FPL) in Madison, Wisconsin as part of its mission to find efficient ways to utilize timber resources (103). The TFS is an engineered structural component that has been patented and is available for use on a royalty-free basis.

For most applications, frames can be made with normal 2 x 4's. Truss frames are normally fabricated in a plant under controlled conditions with great material efficiency. Fast erection may be the greatest attraction of TFS, with the floor, walls, and roof going up as a unit. Buildings can be erected almost as fast as setting conventional roof trusses. Since the system is engineered, it can be designed with larger spacing than the conventional joist-stud construction with resulting material and labor savings (104).

Again, transportation and reduced flexibility are major disadvantages of this technology. The system is especially efficient for the light commercial/industrial construction but is not as attractive for residential construction.

Corrugated Roof, Floor, and Wall Systems

The corrugated waferboard developed at the Alberta Research Council presents an exciting challenge. The board can be tailored in shape based on its application as joists or studs, which it replaces. It can also be used as the web component in a prefabricated SSP to provide higher racking strength than the conventional type, as shown in Fig. 8 (page 50). The enclosed cells of corrugated boards can provide passages for electrical and other conduits.

The major advantage of corrugated boards lies in the ease of forming a variety of unique shapes to use material effectively and speedily perform a variety of specific construction operations. The technology is flexible with no transportation difficulties. Unfortunately, the product is still in its early development stage and more research is needed not only in improving panel strength and performance but also in fabrication techniques, connectors and support technologies.

Wood Building Systems

Wood building systems might be the most exciting challenges for engineers and researchers today. With versatile structural members and sub-systems, it is possible, with architectural and engineering planning, to integrate these products into systems which translate the owner's need into a tangible reality.

These systems can be used to produce a diverse range of buildings in addition to homes, such as small manufacturing plants, garages, storage sheds, etc.. All of which are especially suitable for exporting. Furthermore, the technology could open a vast industrial construction market.

4.4 POTENTIAL AND RESEARCH NEEDED

New wood composite products make more efficient use of our dwindling wood resources with built-up members and structural systems representing advances in this technology. They not only use smaller trees but they also use less of them and in the end produce better and more cost effective structures. However, this technology is relatively new and much more complicated than solid wood or conventional wood composite members; consequently, it will require more reliable engineering, good design, thorough research, and significant capital investment before it can be fully exploited.

Built-Up Members

The success of built-up members is a prerequisite to the future prospect of all structural systems. Current practices and the image of wood construction must be changed before built-up members will be fully adopted in construction. The wood I-beam is a recent success and representative of the potential for this technology. Glulam beams utilizing composite lumber in the tension lamination might also prove to be cost effective. With more reliable engineering information, mechanical connected members may become a viable product for the housing and small scale construction industries. Corrugated waferboard may be used as webs where deep section beams are required.

As for most new products, however, strong R & D is needed for built-up members. Structural performances, engineering supportive information, innovative processes, and marketing studies are important for the acceptance of these products. The use of wood composite panels or lumber in the built-up members is a logic choice, especially in Alberta. Environmental and load duration effects need to be further investigated and the results should be compared with and calibrated against the performance of conventional sawn lumber or glulam members.

Structural Systems

Stressed skin panels have been used in Europe for decades, and with the development of larger flakeboard panels, the system may have a promising future in North America. The stressed skin panels and truss-framed systems may prove to be cost effective for light industrial/commercial construction in which material efficiency and fast erection are more important than the inherent difficulties of limited flexibility and transportation problems.

The corrugated systems and wood building systems are innovative and ultimate concepts. They represent the optimum performance of wood-based materials wherein they are tailored to perform certain tasks within an integrated system or building. This achieves not only material efficiency and construction systematization but also provides great flexibility for engineers and architects pursuing various innovative design ideas. The future development of this technology requires cooperation among the wood industries, designers, researchers and government agencies.

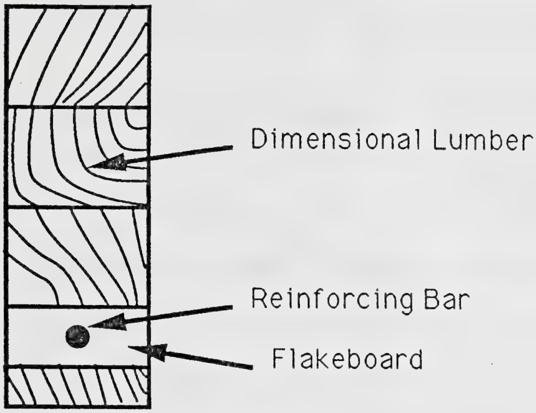


Fig. 5 Steel-Reinforced Glue-Laminated Beam

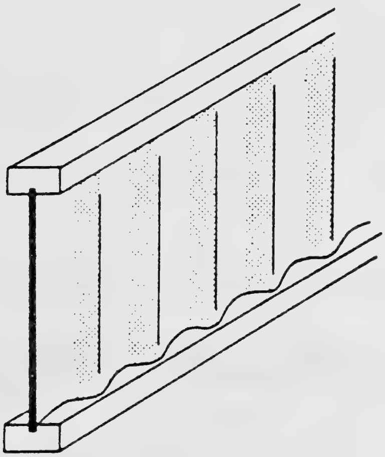
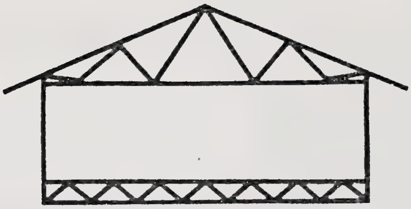
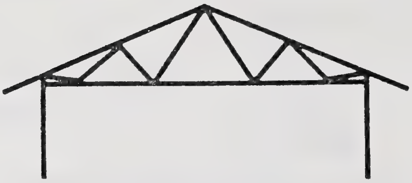


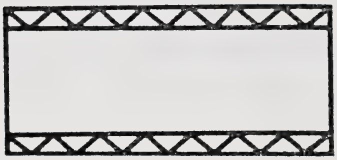
Fig. 6 Wood-I with Corrugated Webbed Beam



Conventional Truss Frame



Partial Truss Frame



Two-Floor Truss Frame

Fig. 7 Typical Truss-Framed Systems

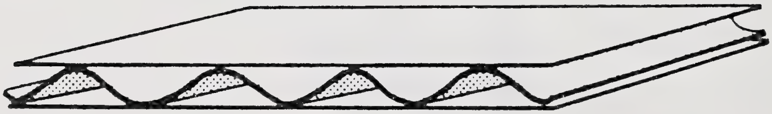


Fig. 8 Stressed Skin Panel with Corrugated Waferboard Web

5.0 EVALUATION, CONSULTATION AND PRIORITIZATION

5.1 EVALUATION OF ENGINEERED WOOD TECHNOLOGIES

This section attempts to rate both known and possible engineered wood products and technologies in terms of their future potential in residential and small scale commercial/industrial construction. The rating in Table 1 (page 57) employs a base rating of "5" against corresponding members or systems used in the conventional wood-frame construction (referred as base products), as indicated in the first row of each category of comparison (e.g. plywood in "Panels" category). A number higher than 5 suggests better prospects than the base product. The first number (under P) considers both short and long term performance. The second number (under T) relates to the current technical status (a low number suggests there is a lot of research to be done). The third number (under A) shows the availability of the material resources or technology in Alberta. The fourth number (under C) gives a cost relative to that of traditional members or systems. The fifth number (under E) suggests the export potential of the product. The last number (under O) predicts the overall potential of the product with the letter L indicating the potential applies more to the long term rather than to the short term.

The categories listed in Table 1 (page 56) are based on various reinforced wood products (panels and lumber), their applications in construction (columns, beams, sheathings, sidings, and interior claddings), and structural systems as a whole. Therefore, some products might be listed under different categories but with different ratings depending upon their comparative performance and cost within that category. A multiple reference indicates a possible wider market and is acknowledged in the products categories (panels and lumber).

5.2 CONSULTATION WITH RESEARCHERS AND WOOD INDUSTRY

The ratings in Table 1 (page 56) were made subjectively based on the information gathered during consultation with researchers and the wood industry. A field trip was undertaken in October, 1990 to the U.S. Forest Products Laboratory, Madison, Wisconsin, one of the major wood research centers in North America. The meetings with over 10 leading research engineers in the laboratory over three days of visit complemented and confirmed the importance and prospects for wood composite and reinforced wood technologies.

Initial ratings, along with a review of Chapters 1 to 4, were presented at a wood industry consultation meeting which took place on January 15, 1991 at University House, University of Alberta. The purpose of the meeting was to consult with knowledgeable wood manufacturers, residential builders, and wood researchers for their evaluation and prioritization of reinforced wood technologies relative to their potential for commercial exploitation and use within Alberta. The agenda of the meeting and the list of attendants are given in Appendix A.

The meeting commenced with a review of the current state of engineered wood and technologies, their challenges and needs. This was followed by a presentation of the summary evaluation and ratings of potential wood reinforcing technologies as listed in Table 1 (page 56). After the presentation, a brainstorming session with the participants identified the top-ranked technologies which might have application to Alberta's forestry and residential construction industries. Future research needs for these products and technologies were also discussed.

The general consensus of the meeting was that recent development in the engineered wood area, especially in wood composites, presented unlimited opportunity and potential for the forest industries, but additional research is needed in these areas. Some attendees stressed economic and marketing studies as being necessary to insure the success of the products. It was also noted that industry initiation is essential to development of new products and technologies. Developments must be market/demand driven not pulled by research. Encouragement and support from the government is also a "must". Some attendees emphasized the importance of the recovery rate from the wood resources, energy efficiency of the new technologies, and use of recycled materials in the potential products.

The meeting concluded with each participant providing a prioritized list of potential engineered wood technologies. The following products and technologies were considered by participants to be of highest priority:

- parallel strand lumber, including long and slender strands as used in parallam and short strands as flakes in OSB.
- Wood I-beam with particleboard web.
- particleboard surfaced with textured fiber
- OSB or waferboard with improved properties and manufacturing processes, and production of large sheet boards.
- wood-plastic composite, especially when recycled plastic is used.

- SSP with particleboard skins and completed with insulation.
- corrugated roof, floor, and wall systems.

Additional products were also listed by some attendees as potential successes:

- parallel laminated veneer
- textured fiberboard (medium density)
- reinforced (composite) glulam timber
- wood box beam with particleboard web
- fiberglass reinforced members
- wood - biomass composite
- wood - cement composite
- mechanical connected members.

5.3 PRIORITIZATION OF ENGINEERED WOOD TECHNOLOGIES

As a consequence of consultation with representatives of government, industry, research institutions, and code bodies, a priority list of engineered wood technologies has been developed. Based on an analysis of the attendees' priority lists and various discussions, five "top priority" products and technologies were chosen and are given below in order of relative importance and current technical status.

1. Particleboards. This includes OSB, waferboard, large sheet particleboard, and particleboard surfaced with textured fiberboard.

2. Wood I- Beams. Specifically prefabricated wood I-beams with particleboard webs.

3. Parallel Strand Lumber. The PSL chosen here includes not only long and slender strands as used in Parallam but also various sizes of strands such as flakes in OSB.

4. Wood Building Systems. These systems are a new, broad design concept wherein various structural sub-systems, such as SSP, truss-framed systems, and corrugated roof, floor, and wall systems, can all be integrated into an overall building system to serve common functions.

5. Wood-Plastic Composites. These include both raw plastic materials and recycled plastic in combination with wood fiber.

These five technologies are discussed in detail in the next chapter. The steps needed to facilitate introduction of the technologies in Alberta and the research required for their commercialization are also addressed.

Table 1 Evaluation of Reinforced Wood Technologies

Reinforced Wood Technologies	Ratings					
	P	T	A	C	E	O
Panels:						
plywood	5	5	5	5	5	5
metal-plywood laminates	7	5	4	3	4	4
metal-particleboard laminates	7	5	4	4	4	4
fiberglass reinforced plywood	7	4	4	3	4	4
fiberglass reinforced particleboard	7	4	4	4	4	4
plastic impregnated wood	4	5	5	4	5	4
particleboard(OSB or waferboard)	5	5	7	7	7	7
fiberboard(low, medium or high density)	3	4	7	7	7	6L
wood-cement composite	6	5	5	3	5	4
veneer-particleboard composite	5	5	5	4	5	4
hardboard-particleboard composite	6	4	7	4	7	6L
wood-biomass composite	4	3	6	5	4	5L
wood-plastic composite	4	3	7	7	7	7L
corrugated waferboard	7	4	7	4	7	6L
Lumber:						
sawn lumber	5	5	5	5	5	5
glulam timber	6	5	5	6	5	5
metal reinforced timber	6	4	4	3	2	3
fiber reinforced timber	6	4	4	3	2	3

Reinforced Wood Technologies	Ratings					
	P	T	A	C	E	O
Lumber:(Con't)						
plastic reinforced timber	4	5	5	4	4	4
parallel laminated veneer(PLV)	7	5	4	3	4	5L
parallel strand lumber (PSL)	6	4	7	6	7	7L
Com-ply lumber	6	5	5	4	5	5L
wood-biomass composite	4	3	6	5	4	5L
wood-plastic composite	4	3	7	6	7	6L
mechanical connected timber	4	4	5	6	5	5
Columns (studs, posts,etc.):						
sawn lumber	5	5	5	5	5	5
glulam timber	5	5	5	6	5	5
PLV	7	5	4	3	4	4L
PSL	6	4	7	6	7	7L
Com-ply lumber	6	5	5	4	5	5L
wood-plastic composite	4	3	7	6	7	6L
mechanical connected member	5	4	5	6	5	6L
Beams (joists, beams, etc.):						
sawn lumber	5	5	5	5	5	5
glulam timber	6	5	5	6	5	5
metal reinforced beam	6	4	4	3	2	3
fiber reinforced beam	6	4	4	3	2	3

Reinforced Wood Technologies	Ratings					
	P	T	A	C	E	O
Beams (joists, beams, etc.):(Con't)						
local reinforced beam(metal or fiber)	6	4	4	4	4	4L
PLV	7	5	4	3	4	5L
PSL	5	4	7	6	7	6L
Com-ply lumber	6	5	5	4	4	5L
shaped particle beam	5	4	6	4	5	5L
wood I-beam(plywood web)	5	5	5	6	6	6L
wood I-beam(particleboard web)	5	4	7	7	7	7L
wood box beam(plywood web)	5	5	5	4	5	5L
wood box beam(particleboard web)	5	4	6	6	6	6L
composite glulam beam(PLV tension lam)	6	5	5	5	6	6L
corrugated webbed beam	6	3	6	5	6	6L
mechanical connected beam	4	4	5	6	5	5L
Sheathing:						
plywood	5	5	5	5	5	5
particleboard	5	5	7	7	7	7
particleboard (large sheet)	6	5	7	7	7	7L
wood-cement composite	6	5	5	4	5	5L
veneer-particleboard composite	5	5	5	4	5	5L
hardboard-particleboard composite	5	4	7	5	6	6L

Reinforced Wood Technologies	Ratings					
	P	T	A	C	E	O
Sidings:						
wood siding	5	5	5	5	5	5
hardboard(medium density)	4	4	7	6	6	5L
hardboard with textured surface	5	4	7	5	6	6L
particleboard surfaced with textured fiber	6	4	7	6	7	7L
textured wood-plastic composite	5	4	7	6	6	6L
Interior claddings:						
gypsum drywall	5	5	5	5	5	5
textured particleboard (large sheet)	5	5	7	4	5	5L
textured fiberboard(medium density)	5	4	7	6	6	6L
Structural systems:						
wood frame construction	5	5	5	5	5	5
stressed skin plywood panel	5	5	5	4	4	4
stressed skin particleboard panel	5	5	6	5	6	5
SSP with particleboard skins & insulation	6	5	6	5	6	6
whole-wall particleboard (textured)	6	4	6	6	6	6L
truss-framed system	5	5	5	6	5	5
corrugated roof, floor, wall systems	6	3	5	6	6	6L
wood building system	7	2	6	7	8	7L

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

Based on the literature review, patent search, and consultation with knowledgeable manufacturers, builders, and researchers, a priority list of five engineered wood technologies or products was developed. The prioritization is based on 1) performance of the reinforced member; 2) current technical status of the technology; 3) availability of the product in Alberta; 4) economies of the product; 5) potential for export of the technology. The five technologies with the greatest potential for commercial exploitation and use within Alberta are:

1. Particleboards. With abundant fast-growing aspens in Alberta, continuous growth in the particleboard industry is predictable. However, intense competition from other products calls for higher quality and broader markets for the panels. Large sheet particleboards and particleboard surfaced with textured fiberboard are two possible examples of future development of particleboards.

2. Wood I-Beams. Recent success enjoyed by the wood I-beams is expected to continue. Nevertheless, more research is needed concerning both the short and long term performances of the product. Acceptance of design standards allowing the use of particleboard in webs, and assignment of design values to the beams themselves are essential for the continued development of the products.

3. Parallel Strand Lumber. PSL is a logical extension of particleboard technology to maximize the wood resources. It can use long and slender

strands to produce a high quality lumber such as Parallam or manufacture strands of various sizes for operational and economic product optimization.

4. Wood Building Systems. Wood building systems can be used to integrate various products such as particleboard, wood I-beam, PSL, SSP, and corrugated waveboard, all of which have been or can be produced in Alberta, to produce economic standard buildings or high quality user-specific building systems.

5. Wood-Plastic Composites. Given Alberta's production of plastic raw material and the abundance of plastic waste generated from the recycle program, wood-plastic composites present an exciting challenge. The products exhibit slow degradation, are light weight, and have improved acoustical, impact, and heat reformability properties.

6.2 CONCLUSIONS AND RECOMMENDATIONS

Wood has been used in building construction since the beginning of human history. The idea of reinforcing timber is not new and laboratory attempts have been successful. Wood is found to be compatible with many materials, such as biomass materials, metals, synthetic fibers, plastic, and even concrete. Nevertheless, due to their cost, most of these ideas have not been developed commercially. In the past two decades, economic pressure, environmental realities, and social policies accompanied with shrinking forest resources have pushed forest industries toward the utilization of all species and sizes, even the smallest trees. This has also demanded their highest value utilization. This has lead to the rapid development of a new generation of wood products - engineered wood products, such as oriented strandboards and wood-I beams.

With abundant fast-growing aspens and the production of other raw materials, such as synthetic resins and plastic, in Alberta, wood composites and modified wood or wood composite products present unlimited opportunities for the forest and wood industries in the province. Strong future research and development of these technologies is essential for their eventual commercialization. Future R & D should emphasize the importance of the recovery rate and efficient use of wood resources, energy efficiency of the new technologies, environmentally friendly products, and the use of the recycled materials. In addition to strong research and development, comprehensive economic and marketing studies were found to be equally important to the eventual success of these new technologies.

Development programs of the five technologies identified as the most important and high priority products in Alberta are proposed individually in the following sub-sections. Future steps to facilitate the introduction of these technologies in Alberta are also recommended. Research plans and suggestions are also provided for those technologies which require further research before they can be commercialized.

6.2.1 PARTICLEBOARDS

A. Introduction

The particleboards referred to here are manufactured from whole logs (mostly pulpwood). When producing particles from this source, it is possible to control the size and shape of the wafers or flakes. Waferboard and oriented strandboard (OSB) are two products requiring the particles to be cut from whole logs. Since the wafers or flakes can be controlled in size and shape, high performance, dimensionally stable panels can be produced. Low energy consumption and renewable and abundant material resources give particleboard advantages over other comparable materials in the construction market.

Fast growth in the particleboard industry, however, suggests a gross oversupply in Canada's sheathing market that might result in lower prices and consequently a lower quality product. It is important to maintain or even improve the quality of the panels to retain their good public image, and to search for broader markets to maintain their viability. Particleboards can be made stronger and stiffer while using less resin and/or energy. They can be produced in larger sheets to speed up construction or in thicker panels to reduce joist spacing and size. Particleboards surfaced with hardboard or textured fiberboard for use as interior panelling, or exterior sidings may have a potential market. However, fire-safety, dimensional stability, and preservative treatments need to be studied further.

B. Product Development.

It is proposed that the future development of particleboard products in Alberta be undertaken in a systematic and sequential manner. The following scenario is one possible option:

Phase I - Quality Control and Production Process

Good quality control of particleboard is essential to the improvement of its otherwise declining public image. This can be achieved by establishing a rigorous grading standard through the Canadian Standards Association which will restore public confidence in the product. In addition, to maximize the advantages of the technology, it is important to continue improving production process and developing alternative adhesive system .

Phase II- Marketing Development

Marketing is necessary to achieve public acceptance of particleboards as a primary construction product, instead of as just a substitute for plywood. Further, given the public's awareness of environment concerns the emphases should be on resource management, energy efficiency, and the environmentally friendly production process of particleboards versus other construction alternatives. .

Phase III- Marketing Studies

Conduct a thorough marketing study of the particleboards' role in the current and future panel and sheathing markets. The market study should include production capability, price, comparative performance, and construction efficiency in all relevant markets such as structural panels, cladding, panelling, and siding. Based on these studies, a long term plan can be established for the continuous research and development of particleboards.

Phase IV- Research and Development

If the forecasts for an oversupply of particleboard hold true, it will be necessary to develop broader markets to ensure its continuing success. Large panels are a logical extension of current 4' x 8' production. It is possible to economically produce thicker and longer span particleboards; furthermore, particleboard can be molded into decorative panelling for house interiors or sidings, both of which represent vast and undeveloped markets. Particleboard can also be surfaced with hardboard or textured fiberboard which improves its toughness, smoothness, and decorability. All of these options require strong R & D before particleboard can tap these virtually unlimited markets.

C. Research Needs

As with most wood composite products, adhesives, processing innovations, and confirmation of product performance are the critical areas of particleboard development which require research.

Adhesive Research - The focus of adhesive research in the years ahead should include: deriving adhesives from renewable resources; developing methods to reduce and possible eliminate formaldehyde emissions; developing adhesives for special uses; and studying the durability and weatherability of alternative adhesive systems.

Manufacturing Process Research - While the global goal of process innovations will be to decrease energy consumption and improve product quality, research into the processing innovations should focus on the following areas: studying the feasibility of using various species in production; developing flaking methods; investigating the quantities and means of resin application; exploring the possibilities of reinforced products; and inventing efficient pressing technologies.

Performance Investigation - The long term performance of particleboards under load and moisture cycling conditions is most critical to the structural performance of the panels. Consequently a comprehensive study of this performance is necessary. Developing performance criteria, rigorous grading and sampling systems are also essential to the understanding of the product and its subsequent wider use. Broad and rigorous performance criteria and a comprehensive test data base for the particleboards must be established, and when coupled with non-destructive testing (NDT) techniques, a simulation of strength distributions, with realization of grading and sampling systems, can be obtained. Fire retardant and preservative treatment investigations are also needed before particleboard can be used in the cladding and siding markets.

6.2.2 Wood I-BEAMS

A. Introduction

Wood I-beams with dimensional lumber flanges and plywood webs are an efficient use of material, and have been used for more than 40 years. Design standards for these components have been available since the early 80's, and technology and facilities have been developed to a degree that prefabricated wood I-beams are a mass produced, economical product. In the last decade, wood I-beams have gained popularity in residential and small scale commercial/industrial construction. They are primarily used as joists in floors and roofs but have also been used as roof support beams, garage door headers, and framing components. Despite the growing public acceptance of wood I-beams in general, and particleboard in particular, industry has been slow to assign standardized design values to particleboard webbed I-beams. The lack of easy to use load tables has precluded particleboard webbed I-beams from being used as primary structural members. The hesitation in assigning design values is primarily attributed to a lack of information on material properties, especially time-dependent behavior. Furthermore, the wood I-beam is a complex assemblage of orthotropic and isotropic materials. The static strength of I-beams is influenced by the strength and stiffness of the composite materials, adhesive strength and stiffness, web opening and connection details. Since wood I-beams are an efficient, stiff and low mass element, stability and dynamic performance are more important design considerations than those of sawn lumber or glulam timber beams, in which stability and dynamic problems are normally considered as minor.

B. Product Development

The major factor hindering the greater use of these wood I-beams is the wood I-beam itself. More research is needed into its performance such as static, dynamic and long term performance and reliability of these components.

The following actions are required to enhance the development of the particleboard webbed I-beams.

Phase I - Performance Tests and Criteria for Prefabricated Wood I-Beams with Particleboard Web

Standard procedures must be established through cooperations among industry, researchers, and government agencies to monitor and evaluate structural performances of prefabricated wood I-beams with particleboard web. The new ASTM wood I-joist standard (87) can be used as a draft guideline. A standard will eliminate the inconsistencies in performance of wood I-beams among different manufacturers, resulting in a more uniform and reliable product with corresponding improvements in public confidence. The procedure can also reduce the burden of extensive testing and evaluation before new producers can enter the market.

Phase II - Comprehensive Research Programs

Establish a comprehensive research program to investigate the behaviour of wood I-beams fabricated with Alberta woods. The research plan should start by compiling available testing data and research results, and be followed by field and laboratory investigations. The research programs must include short- and long-term static testing. The short-term static research should address the influence of various flange and web materials and web orientation, reinforcement, openings and joints plus the influence of the flange-web joint. Long-term evaluation should consider the critical issues of environmental and load duration effects. Both laboratory and field investigations are needed to produce realistic designing models of long-term performance and to understand the beam durability and the effect of moisture content. The research programs should be joint projects among industry, government agencies, research institutes, and university academics.

Phase III - Design Standards Development

The Canadian Standard Association should be asked to develop standard design tables for wood-I beams which would include the use of Alberta woods. A comprehensive design procedure for the use of wood I-beams should be prepared by the industry as a complementary document to the design values of wood I-beams.

Phase IV - Further Development of Wood I-Beams

With future development of composite lumber and corrugated waferboard, high performance wood I-beams can be produced as primary structural members. A long-term research and development program should be established for high performance wood I-beams using Alberta's high grade composite lumber and panels or corrugated waferboards. This product is especially attractive for low-rise commercial/industrial buildings.

6.2.3. Parallel Strand Lumber

A. Introduction

Parallel strand lumber (PSL) is a logical extension of Alberta's particleboard technology. It can be manufactured from long and slender strands to produce a high quality of bending members such as Parallam or produced with various sizes and shapes of strands or flakes to achieve economic and performance optimization. The PSL technology can utilize fast-growing Alberta aspens to produce lumber with consistent grain- and knot-free uniformity and tailored utility that solid woods lack. The present particleboard industry can be modified to produce PSL which is less expensive than the parallel laminated veneers (PLV) which are processed in a manner similar to plywood. The performance of PSL can easily be improved by varying the size and shape of strands or flakes, or by reinforcing the product with non-wood materials such as fiberglass.

As with most of particleboard products, PSL needs research in adhesive , processing, and performance documentation. Unlike particleboards, however, there is very little information available concerning the manufacture and performance of PSL. The only product available on the market, Parallam, is relatively expensive and not readily available in Alberta.

The PSL proposed herein is designed for a wide variety of markets; it can be used as 2 x 4 studs in wood-frame construction or as larger dimensional lumber posts and bending members. It can also be applied to other composite products such as wood I-beams or Com-ply lumber. It is expected that the demand for PSL will increase as the supply of high quality lumber decreases. The prospects for the PSL are more to the long term than to the short.

B. Product Development

Since the PSL technology is relatively new, construction of a pilot plant is recommended. The existing facilities and particleboard technology of the Forest Products Laboratory at the Alberta Research Council could be utilized to investigate the feasibility of developing PSL technology in Alberta. The product development program could include the following steps.

Phase I - Exploitation Stage

Explore potential commercially viable techniques for manufacturing PSL utilizing Alberta aspens. Conceive, design and construct a pilot plant using the existing facilities and technology available at the Alberta Research Council. Develop a manufacturing process suitable for the laboratory manufacture of PSL 2 x 4's. The focus of the manufacturing process should be the use of less resin and energy.

Phase II - PSL Performance Investigation

Develop a research program to investigate the long- and short-term performance of PSL manufactured using the process developed from Phase I. The program should address the following parameters: strand or wafer geometry; resin type and content; pressing time and heat; lumber density; and other possible additives.

Phase III - Cost and Market Analysis

Perform a detailed cost analysis for the commercial production of PSL and compare it with competitive products. Conduct a thorough market study and comparison of PSL versus sawn lumber, glulam timber, and composite lumber regarding their production capability, long term resource availability, and performance. If the results are favourable, develop a plan for the future development and production of PSL in Alberta.

6.2.4 Wood Building Systems

A. Introduction

In wood building systems, the individual material elements are tailored to perform specific tasks while being integrated into a building. This satisfies not only material efficiency and construction systematization but also provides flexibility for designers to utilize innovative ideas. Wood building systems represent the ultimate design concept and an optimum performance of the wood-based materials.

Wood building systems are generally used to produce standard buildings to meet specific end uses, such as small manufacturing plants, garages farm buildings, and low-cost residential housing. These products are especially suitable for export. The systems can also be used in user-specific applications.

Recent developments, such as wood I-beams, stressed skin panels, truss-framed systems, and corrugated waferboards, can all be integrated to produce functional, efficient, and economical wood building systems.

B. Technology Development

It is proposed that wood products and systems developed and produced in Alberta be used in a development program to design and build a prototypical house. Up-to-date engineering design concepts would accommodate wind loads, snow loads, shear diaphragm action, etc. The building will be used as a basis for comparing the cost and performance of wood building systems to those of conventional wood-frame construction. The development program could contain the following elements:

Phase I - Engineering Design

Analyze and compare the cost and performance of the available wood products and sub-systems in Alberta. Based on the engineering information from each product and up-to-date engineering design concepts, design and cost a prototypical house which maximizes each product's contribution. A cost analysis is made based on the design. The cooperation among builders, wood products industries, designers, researchers, and government agencies is essential to the success of this program, but the potential benefits merit the effort. The project will not only benefit our residential construction and wood products manufacturing industries but can also improve the public image of the wood construction industry as a whole.

Phase II - Construction

Construct the prototypical house and record the costs and construction process and timing.

Phase III - Observation

Design and implement experimental investigations of the systems' short- and long-term performance. Based on the results and observations during this period, modifications to the system can be made to improve its performance.

Phase IV - Marketing Studies

Conduct a marketing study for the system. The study should include price and performance comparisons, construction efficiency, and especially the potential for export. Based on the results of the study, a long term program can be established for marketing the system and future development of other potential building systems.

Phase V - Conclusion of the Project

Prepare a detailed analysis and comparison of cost, performance, and construction efficiency of the prototypical house versus those of a conventional wood-frame construction. Based on the results of this investigation, a low cost, functional house with export potential can be developed. The findings and experience from this study can also be applied to other types of wood structural systems.

6.2.5 Wood-Plastic Composites

A. Introduction

Plastic has long been used as a reinforcement in wood products to improve their hardness, abrasion resistance, and compression strength, with parquet flooring being a major commercial example. The products are sometimes referred to as wood matrix-plastic composites, in which solid wood or veneers are saturated with a monomer and polymerized in-situ or impregnated with a preformed polymer. The other wood-plastic combinations, which will be the focus of this development program, are those composites where wood particles and plastic are mixed together and the plastic melts acting as a "glue", but each component remains as a distinct phase.

The wood-plastic composites discussed here are manufactured from Alberta's raw and recycled wood (especially hardwood) and plastic. Two abundant plastic wastes are easily recovered and offer excellent potential as low-cost resins. They are high-density polethylene (HDPE) milk containers and polethylene terephthalate (PET) beverage containers. Recycled PET fibers can be used for property enhancement, while HDPE can serve as a matrix polymer. The use of modern blending equipment permits mixing of plastic and wood components. This mixture can be extruded or injection-molded into its final configuration. However, adequate bonds between these two dissimilar materials remains a problem. Furthermore, the low modulus of elasticity for plastic might prevent the composites from being a high performance product unless other performance materials are added.

This product is particularly attractive under today's environmental pressure because of the use of our ample supply of renewable and recycled materials. Composites combine the beneficial aspects of each constituent component. The wood is strong, light weight, nonabrasive, nonhazardous, blendable, and cost effective. The plastic has good abrasive resistance, dimensional stability, light weight, slow degradation, and homogeneity of compressive properties. The products can be used in temporary housing structures, panelling for interior walls or partitions, and floor, wall, and roof systems for light frame construction.

B. Product Development

There is very little research data concerning wood-plastic composites. However, the technology does exist in the plastic and wood industries. A development program could include the following elements:

Phase I - Exploitation Stage

The program should start by compiling information on plastic and wood technologies, identifing those which appear to have application in Alberta. The investigation should include sources of available plastic and wood raw materials in the province.

Phase II - Process Technologies and Performance Investigation

Based on the information gathered in Phase I, a pilot plant and research program could be established using existing facilities, and technology available in Alberta's particleboard industries and research institutes. The project should be a cooperative program among industries, research institutes and universities, each of which already studies related process technologies and products. In addition to the innovative process techniques, the research program should address the following problems: wood particle geometry; types and content of plastic, mixing; heating and pressing time; mechanical and long-term performance; and other performance enhancement possibilities.

Phase III - Economic and Market Research

Perform a detail cost analysis of any proposed wood-plastic composites. A comparison of present and future prospects of competitive products should be considered. A reliable supply of raw materials must also be investigated. Finally, a marketing study and long-term development program for the various products produced with wood/plastic technologies can be planned and executed.

BIBLIOGRAPHY

1. "Canada's Forest Industry: the Next Twenty Years: Prospects and Priorities (Volume IV: Wood Products)" by Woodbridge, Reed & Associates.

2. Dietz, G.R., 1966. "Wood Plastic Combination Irradiated Wood" Industrial Finishing, Vol. 42, April pp. 106-108.

3. Bulleit, W.M., 1984. "Reinforcement of Wood Materials: A Review" Wood and Fiber Science, 16(3), pp. 391-397.

4. McKnight, T.S., 1974. "Wood Composite Products Evolution, Major Demands and Opportunities", Information Report DPC-X-3, Program Development Branch, Canadian Forestry Service, Department of the Environment, Ottawa, 40P.

5. Leitch, R.J., Falk, R.H., and Laufenberg, T.L., 1990. "Prefabricated Wood Composite I-beams: A Literature Review", Wood and Fiber Science, 22(1). pp 62-79.

6. Bach, L. and Cheng, J.J., 1990. "Full-Scale Tests of OSB Stressed Skin Panels", CSCE Annual Conference, Hamilton, Ontario, May.

7. Mark, R., 1961. "Wood-Aluminum Beams Within and Beyond the Elastic Range-I. Rectangular Sections", Forest Products Journal, October pp. 477-484.

8. Mark, R., 1963. "Wood-Aluminum Beams Within and Beyond the Elastic Range - II. Trapezoidal Sections", Forest Products Journal, November, pp. 508-516.

9. Sliker, A., 1962, "Reinforced Wood Laminated Beams", Forest Products Journal, February, pp. 91-96.

10. Kumar, V.K., Stern, E.G., and Szabo, T., 1972. "Built-up Composite Beams", V.P.I. Research Division Wood Research and Construction Lab. Report No. 110.

11. "Farm Building Handbook", 1969. Structures Pub. Co., 32580 Grand River Ave., Farmington, Michigan.

12. "The NAHB Beam Manual", 1964. National Association of Home Builders, 1625 L Street, N.W. Washington, D.C.

13. Lantos, G., 1970. "The Flexural Behaviour of Steel Reinforced Laminated Timber Beams", Wood Science, 2(3), January pp. 136-143.

14. Hoyle, R.J., 1975. "Steel-Reinforced Wood Beam Design", Forest Products Journal, 25(4), April, pp. 17-23.

.15 Bohannan, B., 1962. "Prestressed Wood Members", Forest Products Journal, 12(12), December, pp. 596-602.

16. Bohannan, B., 1964. "Pressed laminated Wood Beams", U.S. Forest Service Paper FPL8, Forest Products Lab. Madison, Wis.

17. Bohannan, B., 1974, "Time Dependent Characteristics of Prestressed Wood Beams", U.S. Forest Service Research Paper FPL 226. Forest Products Lab. Madison, Wis.

18. Peterson, J., 1965, "Wood Beams Prestressed with Bonded Tension Elements", Journal of the Structural Division, ASCE. 91 (STI), February, pp. 103-119.

19. Coleman, G.E. and Hurst, H.T., 1974. "Timber Structures Reinforced with Light Gage Steel", Forest Products Journal, 24(7). July, pp. 45-53.

20. Vincent, T.A. and Gopu, V.K.A., 1985, "Rational Design of Radial Reinforcement in Pitch-Cambered Glulam Beams", Forest Products Journal, 35(1), January, pp. 61-67.

21. Gopu, V.K.A., 1981. "Repaired Pitch-Cambered Glulam Beams", Journal of the Structural Division, ASCE, 107(ST7), July, pp. 1251-1262.

22. "Composite Material: Metal Wood Laminates", 1967. Material in Design Engineering, Vol. 64, p.466.

23. Rawlands, R.E., Deweghe, R.P.V., Laufenberg, T.L., and Krueger, G.P., 1986. "Fiber-Reinforced Wood Composites", Wood and Fiber Science, 18(1), pp. 39-57.

24. Wangaard, F.F., 1964. "Elastic Deflection of Wood-Fiberglass Composite Beams", Forest Products Journal 14(6). pp. 256-260.

25. Biblis, E.J., 1965 "Analysis of Wood-Fiberglass Composite Beams Within and Beyond the Elastic Region", Forest Products Journal, 15(2). pp. 81-88.

26. Thenkston, F.H., 1965. "A Feasibility Study for Strengthening Timber Beams with Fiberglass" Canadian Agricultural Engineering, January, pp. 17-19.

27. Tang, R.C. and Adams, S.F., 1973. "Applications of Reinforced Plastics for Laminated Transmission Poles", Forest Products Journal, 23(10), pp. 42-46.

28. Spaun, F.D., 1981. "Reinforcement of Wood with Fiberglass", Forest Products Journal, 31(4), pp. 26-33.

29. Larson, D.S., 1981. "The Technical and Marketing Feasibility of Producing Synthetically Reinforced Parallel Laminated Veneer Material", Master thesis, Michigan Technological University, Houghton, M1.

30. "Plywood Overlaid with Fiberglass - Reinforced Plastic" Basic Panel Properties" 1972. APA Lab Report 119, Part 1. APA. Tacoma, WA.

31 Poplis, J.A. and Mitzner, R.C., 1973. "Plywood Overlaid with Fiberglass - Reinforced Plastic: Fastener Tests", APA Lab Report 119. Part 2, APA, Tacoma, WA.

32. Mitzner, R.C., 1973. "Plywood Overlaid with Fiberglass Reinforced Plastic: Durability and Maintenance", APA Lab. Report 119. Part 3, APA, Tacoma, WA.

33. Bulleit, W.M., 1985. "Elastic Analysis of Surface Reinforced Particleboard", Forest Products Journal. 35(5), pp. 61-68.

34. Krueger, G.P. and Sandberg, L.B., 1974. "Ultimate-Strength Design of Reinforced Timber: Evaluation of Design Parameters Wood Science, 6(4), pp. 316-329.

35. Krueger, G.P. and Eddy, F.M., 1974. "Ultimate-strength Design of Reinforced Timber: Moment Rotation Characteristic", Wood Science, 6(4). pp. 330-344.

36. Kobetz, R.W. and Krueger, G.P., 1976. "Ultimate-Strength Design of Reinforced Timber: Biaxial Stress Failure Criteria", Wood Science, 8(4), pp. 252-262.

37. Meyer, J.A., 1982. "Industrial Use of Wood-Polymer Materials: State of the Art", Forest Products Journal 32(1), pp. 24-29.

38. Meyer, J.A. 1981. "Wood-Polymer Materials: State of the Art", Wood Science, 14(2), pp. 49-54.

39. Krueger, G.P., 1973. "Ultimate-Strength Design of Reinforced Timber-State of the Art", Wood Science 6(2), pp. 175-186.

40. Borgin, K.B., Loedolff, G.F., and Saunders, G.R., 1968. "Laminated Wood Beams Reinforced with Steel Strips", Journal of the Structural Division, ASCE, 94(ST7), July, pp. 1681-1705.

41. Carroll, M.N., 1963. "Efficiency of Urea - and Phenol-Formaldehyde and Particleboard", Forest Products Journal, 13(3), pp. 113-120.

42. Youngquist, J.A., Carll, C.G., and Dickenhoof, H.E., 1982. "U.S. Wood-Based Panel Industry: Research and Technological Innovations", Forest Products Journal, 32(8), pp. 14-24.

43. Carll, C., 1986. "Wood Particleboard and Flakeboard - Types, Grades and Uses", General Technical Report FPL-GTR-53, U.S. Forest Products Lab. Madison, Wis.

44. Carroll, M.N., 1976. "Growth of Waferboard in Canada", Forest Products Journal. 26(11), pp. 26-30.

45. American National Standards Institute, 1979. "Mat-Formed Wood Particleboard", ANSI A208.1, New York, N.Y.

46. Canadian Standards Association. 1985. "Mat-Formed Wood Particleboard", CSA-0188-1985, Rexdale, Ontario.

47. American Plywood Association, 1984. "Performance Standards and Policies for Structural Use Panels" APA, E445H. Tacoma, Wash.

48. Singh, B.K., Nautiyal, J.C., and Samama, Y.S., 1988. "An Economic Study of the Demand for Nonveneered Structural Panels in Canada", Forest Products Journal, 38 (11/12), pp. 15-22.

49. American Society for Testing Materials, 1978. "Standard Definitions of Terms Relating to Wood-Base Fiber and Particle Panel Materials" ASTM D1554. Philadelphia, PA.

50. Myers, G.C. and NcNatt, J.D., 1985. "Fiberboard and Hardboard Research at the Forest Products Laboratory", General Technical Report FPL-47, U.S. Forest Products Lab., Madison, Wis.

51. Johnson, J.A. and Montrey, H.M., 1980. "Fiberboard: Its Role as a Building Material", AICHE Symposium Series, No. 195. Vol. 76.

52. Steinmetz, P.E., 1977. "Resin Systems and Glass Reinforcements to Improve Dry-Formed Hardboards", USDA Forest Service Research Paper FPL 284. U.S. Forest Products Lab., Madison, Wis.

53. Biblis, E.J., 1989. "Engineering Properties of Commercial Hardboard Siding. Par 1. Embossed Panels", Forest Products Journal. 39(9). pp. 9-13.

54. Lee, A.W.C., 1985. "Effect of Cement/Wood Ratio on Bending Properties of Cement-Bonded Southern Pine Excelsior Board", Wood and Fiber Science, 17(3). pp.361-364.

55. Moslemi, A.A. and Pfister, S.C., 1987. "The Influence of Cement/Wood Ratio and Cement Type on Bending Strength and Dimensional Stability of Wood-Cement Composite Panels" Wood and Fiber Science, 19(2), pp. 165-175.

56. Moslemi, A.A. and Lim, Y.T., 1984. "Compatibility of Southern Hardwoods with Portland Cement", Forest Products Journal. 34(7/8). pp. 22-26.

57. Miller, D.P. Moslemi, A.A. and Short, P.H., 1989. "The Use of Fly Ash in Wood-Cement Composites", Forest Products Journal, 39(9), pp. 34-38.

58. Buys, H., "Construction and Construction Elements with Wood-Cement Particleboards."

59. Batey, T.E. Post, P.W., Matteson, D., and Ziegler, G.A., 1975. "Flexural Design Procedure for the Composite Panel", Forest Products Journal 25(9), pp. 49-55.

60. Countryman, 1975. "Research Program to Develop Performance Specifications for the Veneer-Particleboard Composite Panel", Forest Products Journal, 259(), pp. 44-48.

61. McKean, H.B., Snodgrass, J.D. and Saunders, R.J., 1975. "Commercial Development of Composite Plywood", 25(9). pp.63-68.

62. Mock, J.A., 1979. "Wood Composites", Material Engineering, 89(5), pp. 60-63.

63. Smulski, S.J. and Ifju, G., 1987. "Flexural Behavior of Glass Fiber Reinforced Hardboard", Wood and Fiber Science, 19(3), pp. 313-327.

64. Smulski, S.J. and Ifju, G., 1987. "Creep Behavior of Glass Fiber Reinforced Hardboard", Wood and Fiber Science, 19 (4), pp. 430-438.

65. Haygreen, J.G. and Bowyer, J.L., "Forest Products and Wood Science", 2nd Edition, Iowa State University Press.

66. Laufenberg, T.L., 1983. "Parallel-Laminated Veneer: Processing and Performance Research Review", Forest Products Journal, 33(9), pp. 21-28.

67. Kunesh, R.H., 1978. "MICRO=LAM: Structural Laminated Veneer Lumber", Forest Products Journal. 28(7), pp. 41-44.

68. Fraser, H.R., 1981. "Laminated Timber Product Makes Debut in Finland", World Wood, 21(5), pp. 39.

69. Schaffer, et al. 1972. "Feasibility of Producing a High-Yield Laminated Structural Product - General Summary", USDA Forest Service Research Paper FPL 175, O.U.S., Forest Products Lab, Madison, Wis.

70. Harpcle, G.B. and Aubry, L.W., 1977. "Economic Feasibility of Process for High-Yield Laminated Structural Products", U.SDA Forest Service Research Paper FPL 285, U.S. Forest Products Lab., Madison, Wis.

71. Building Officials and Code Aministrators, Int. 1980. "Lamineer 22 Ft Tension Ply Lumber" Research Report 79-33.

72. Laufenburg, T.L., Rowlands, R.E. and Krueger, G.P., 1984. "Economic Feasibility of Synthetic Fiber Reinforced Laminated Veneer Lumber (LVL)", Forest Products Journal, 34(4). pp. 15-22.

73. Spaun, F.D., 1981. "Reinforcement of Wood with Fiberglass". Forest Products Journal 31(4), pp. 26-33.

74. Youngquist, J.A., Laufenberg, T.L., and Bryant, B.S., 1984. "End Jointing of Laminated Veneer Lumber for Structural Use", Forest Products Journal, 34(11/12), pp. 25-32.

75. Larson, et. al., 1987. "Butt Joint Reinforcement in Parallel-Laminated Veneer (PLV) Lumber", Wood and Fiber Science, 19(4), pp. 414-429.

76. Saucier, J.R. and Holman, J.A., 1975. "Structural Particleboard Reinforced with Glass Fiber - Progress in Its Development", Forest Products Journal. 25(9). pp. 69-72.

77. Blomquist, R.F., Duff, J.E. and McAlister, R.H., 1975. "Com-Ply Studs - A Status Report", Forest Products Journal, 25(9). pp. 34-43.

78. Koenigshof, G.A., 1979. "Status of Com-Ply Floor Joist Research", Forest Products Journal 29(11), pp. 37-42.

79. Bach, L., 1989. "Manufacture of Corrugated Waferboard", Forest Products Journal, 39(10), pp. 58-62.

80. Geimer, R.L. and Lehmann, W.F., 1975. "Product and Process Variables Associated with a Shaped Particle Beams", Forest Products Journal, 25(9) pp. 72-80.

81. Youngquist, J.A. and Rowell, R.M., 1989. "Opportunities for Combining Wood with Nonwood Materials", Proceedings of the 23rd International Particleboard/Composite Materials Symposium, April 4-6, Pullman, WA. pp. 141-157.

82. Klason, C. Kubat, J., and Stromvall, H.E., 1984. "The Efficiency of Cellulosic Fillers in Common Thermoplastics, Part I, Filling Without Processing aids or Coupling Agents", International Journal of Polymeric Mater, 10(3), pp. 159-187.

83. Heebink, B.G., 1972. "Some Views on Large Structural Particleboard Panels", USDA Forest Service Research Note FPL220, U.S. Forest Products Lab Madison, Wis.

84. CMHC, "Canadian Wood Frame Construction", Canadian Mortgage and Housing Corporation.

85. Canadian Standard Association, 1989. "Engineering Design in Wood" CAN 3-086.1-M89.

86. Nelson, S.A., 1975. "Prefabricated Wood Joists" in Wood Structures: A Design Guide and Commentary, ASCE Structural Division, New York, pp. 213-215.

87. ASTM, 1988 "Standard Specification for Establishing and Monitoring Structural Capacity of Prefabricated Wood I - Joists", Draft (December 1988). ASTM. Philadelphia, PA. 50 p.

88. APA, 1982. "Design and Fabrication of Plywood-Lumber Beams", American Plywood Association, Tacoma, WA.

89. Leichti, R.J., Falk, R.H. and Laufenber, T.L., 1990. "Prefabricated Wood Composite I-beams: A Literature Review", Wood and Fiber Science , 22(1), pp. 62-79.

90. McNatt, J.D., 1980. "Hardboard - Webbed Beams: Research and Application", Forest Products Journal (30(10), pp. 57-64.

91. Superfesky, M.J. and Ramaker, T.J., 1976. "Hardboard-Webbed I-beams subjected to Short-Term Loading", USDA Forest Service Research Paper FPL 264, U.S. Forest Products Lab., Madison, Wis.

92. McNatt, J.D. and Superfesky, M.J., 1983. "Long-Term Load Performance of Hardboard I-beams", USDA Forest Service Research Paper FPL441, U.S. Forest Products Lab., Madison, Wis.

93. Leichti, R.J. and Tang, R.C. 1989. "Comparative Performance of Long-Term Loaded Wood Composite I-Beams and Sawn Lumber", Wood and Fiber Science, 21(2), pp. 142-154.

94. Hunt, M.O., 1975. "Structural Particleboard for Webs of Composite Beams".

95. Bannister, A., 1970. "Torsion of Rectangular Box Sections of British Structural Plywood", Civil Engineering and Public Works, Review, October, pp. 1150-1163.

96. Bulleit, W.M., Sandberg, L.B. and Woods, G.J., 1989. "Steel-Reinforced Glued laminated Timber", Journal of Structural Engineering, 115(2), February, pp 433-444.

97. Emmanuael, J.H., Newhouse, C.M., and Brakeman, D.B., 1987. "Investigation of Metal-Plate-Connected Double 4 by 2 Beams", Forest Products Journal, 37(11/12), pp. 75-79.

98. Winistorfer, S.G., Moody, R.C. and Cramer, C.O., 1987. "Bending Performance of Spliced Nailed-Laminated Posts", Transactions of the ASAE, 30(6), pp. 1791-1796.

99. Council of Forestry Industries of British Columbia (COFI), 1976. "Plywood Construction Manual", 3rd Edition, COFI, Vancouver, Canada.

100. Atherton, G.H., 1983. "Ultimate Strength of Structural Particleboard Diaphragms", Forest Products Journal, 33(5), pp. 22-26.

101. "Seven S-3000 Panel System", Seven S Structures Inc.

102. Wong, P.C.K., Bach, L., and Cheng, J.J., 1988., "The Flexural Creep Behaviour of OSB Stressed Skin Panels", Structural Engineering Report 158, Civil Engineering Department, University of Alberta.

103. "Truss-Framed System" USDA Forest Service, U.S. Forest Products Lab, Madison, Wis.

104. Tuomi, R.L., Hans, G.E., and Stith, D.J., 1983. "Fabrication, Transportation, and Erection of the Prototype Truss-Framed House", USDA Forest Service, U.S. Forest Products Lab., Madison, Wis.

APPENDIX A - AGENDA AND ATTENDEES OF THE CONSULTATION MEETING

Wood Industry Consultation Meeting

Reinforced Wood Members: Analysis and Prospect

January 15, 1991

University House, University of Alberta

2:00 - 4:00 P.M.

AGENDA

- Opening Remarks
- Introduction by Attendees
- Review of Reinforced Products & Technologies
- Summary of Evaluation of Potential Wood Reinforcing Technologies

COFFEE BREAK

- Workshop - Brainstorming Session
  - Reinforcing Technologies: Reinforced Wood Components, Wood Composites, Built-Up Members & Structural Systems
  - Reinforced Wood Products: Panels, Lumber, Members, Systems
  - Wood-Frame Construction: Studs, Joists, Posts, Beams, Sheathings, Sidings, Claddings, Structural Systems
- Summary of the Workshop
- Meeting Concludes

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